December 1958

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NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION

CRITICAL FACILITIES

A NUCLEONICS Report...page 39

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VOLUME 16 NUMBER 12

DECEMBER 1958

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About NUCLEONICS

Season's Greetings

Lest those for whom we strive should think
That in our veins there flows but ink,
We let our season's cheer outpour
From Windscale's piles to Livermore.

We'll dance around the Christmas tree
And all find gifts from AEC—
Consider this most thankfully:
They're budgeted by JCAE.
Then a minuet let's dance
With Graham, McCone and Harold Vance.
And now we'll trip a step or two
With Libby and John Floberg, too!
With cup raised high, let us pause
For Davis, Fields and L. L. Strauss.
Carol now in unison,
Hickenlooper, Anderson;
Join the chorus, Albert Gore,
Holifield and many more.
Wise men, follow Chauncey Starr
And dance about the OMR.
Gather 'round the wassail bowl,
Wally Zinn and Sterling Cole,
Homi Bhabha, Kurchatov,
Sir Edwin Plowden and Emelyanov,
And drink a toast, sure all concur,
To salty Hyman Rickover.
Deck Calder Hall, send paeans aloft
For Sirs Chris Hinton and John Cockcroft.
Richard Post, tuck in your bib
And share plum pudding with Sir Claude Gibb
Hearty greetings, Jim Ramey,
Charlie Weaver and Jim Beckerley
Gunnar Randers sends wishes galore
To Queen Frederika and Niels Bohr.

Paul Aebersold, come fill your mug
At Sigvard Eklund's bowl of glög,
And of good cheer let's loose a flood,
John Landis, Merril Eisenbud,
Leland Haworth, Norris Bradbury,
Alvin Weinberg and Norman Hilberry.
Here's to Phil Sporn's health in Schlitz,
And likewise Bernie Manowitz.
Happy New Year, Charles Coryell,
R. L. Doan and Ned Trapnell.
Chant a joyous Christmas tune
For Glenn Seaborg and Frank McCune.
Can our party boast a quorum
Without Robbins and his Forum?
Down into the cool wine cellar,
Get the best for Edward Teller:
Ruby port for John R. Menke,
Henry Smyth and Al Luedecke;
For Walker Cisler, fine chablis,
For Jim Tuck and Edith Quimby.
Hesitate not to predict
Good health for Manson Benedict.
Open a bottle of rare old Kirsch
For Louis Armand and Etienne Hirsch.
C. McCullough and P. R. Bell,
Succumb with us to the season's spell
While we raise a happy din
To wish good cheer to Francis Perrin,
W. B. Lewis and Frank Pittman,
C. Allardice and Jimmy Fairman.

The year now slowly fades from view;
Its blessings have not been too few—
Nautilus sailed 'neath Arctic ice,
Radioisotopes dropped in price,
Fusion facts have been released,
Geneva enclaved the West and East.
The future should not make us glum—
Ahead lies a nuclear Elysium.

[*Alas! We know of many friends*
We'd like to list before this ends,
But limited by space and rhyme,
We must commit omission's crime.] —T.L.C.

Coming Features in NUCLEONICS

Next Month

High-Power Operation of EBWR

Fission Counters As Reactor Monitors

Neutron Cross Sections Data

Later Months

Army Reactors Program

Beta Counting Efficiency

Zircaloy-2 Properties

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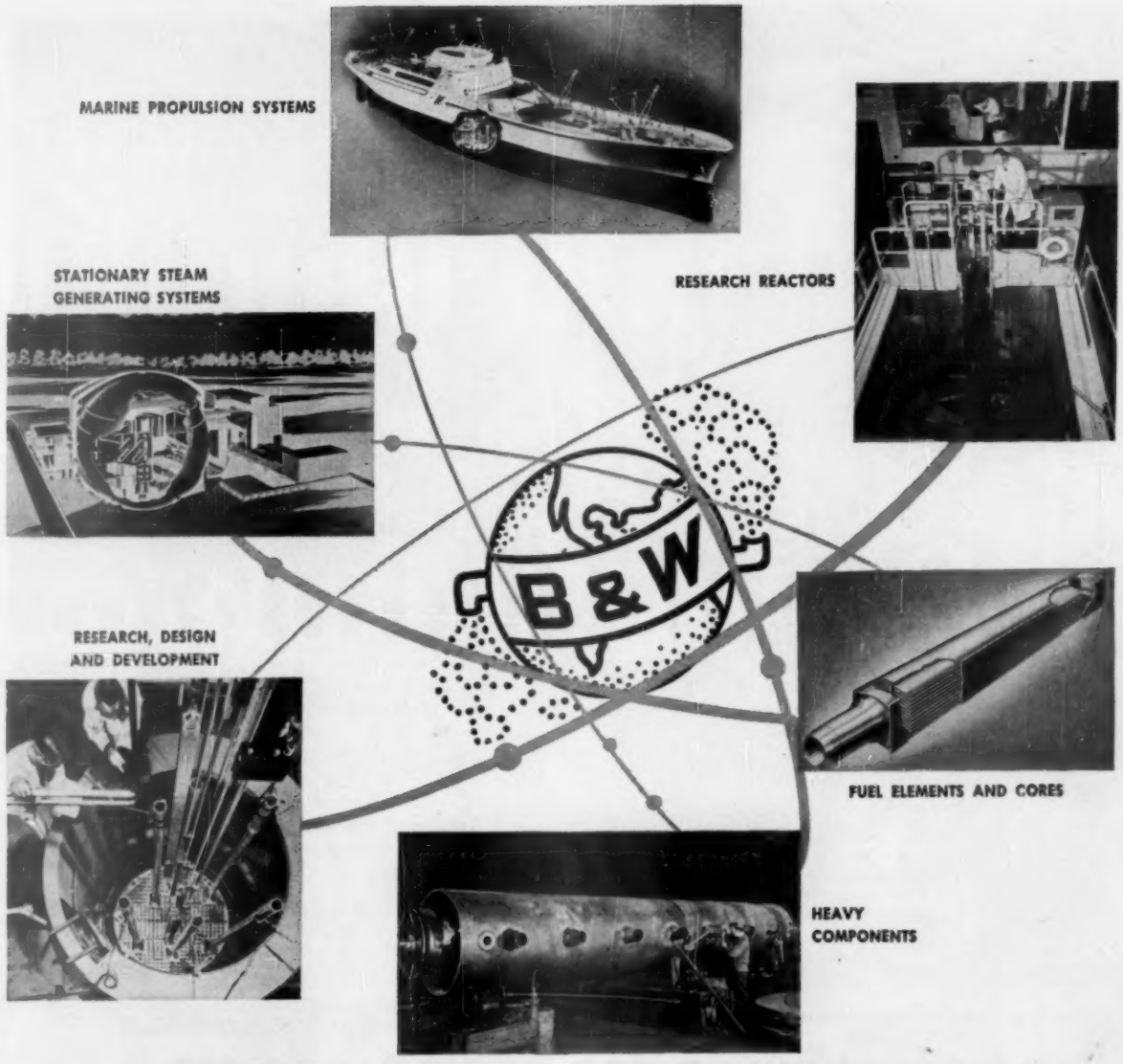

Some Of The Major Areas In Which B&W Is Contributing To Nuclear Reactor Development

From fuel elements to complete nuclear steam generators, Babcock & Wilcox is actively engaged in all phases of nuclear reactor development.

A skilled staff of scientists and engineers, specialized production facilities, programs of research for nuclear applications, together with long experience in controlling heat and pressure for productive purposes, have combined to establish B&W's position of leadership in putting the atom to useful work.

B&W recognizes that the development of nuclear power challenges industry with unprecedented, complex problems and is contributing to their solution—and to the Free World's progress and strength. The Babcock &Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, New York.

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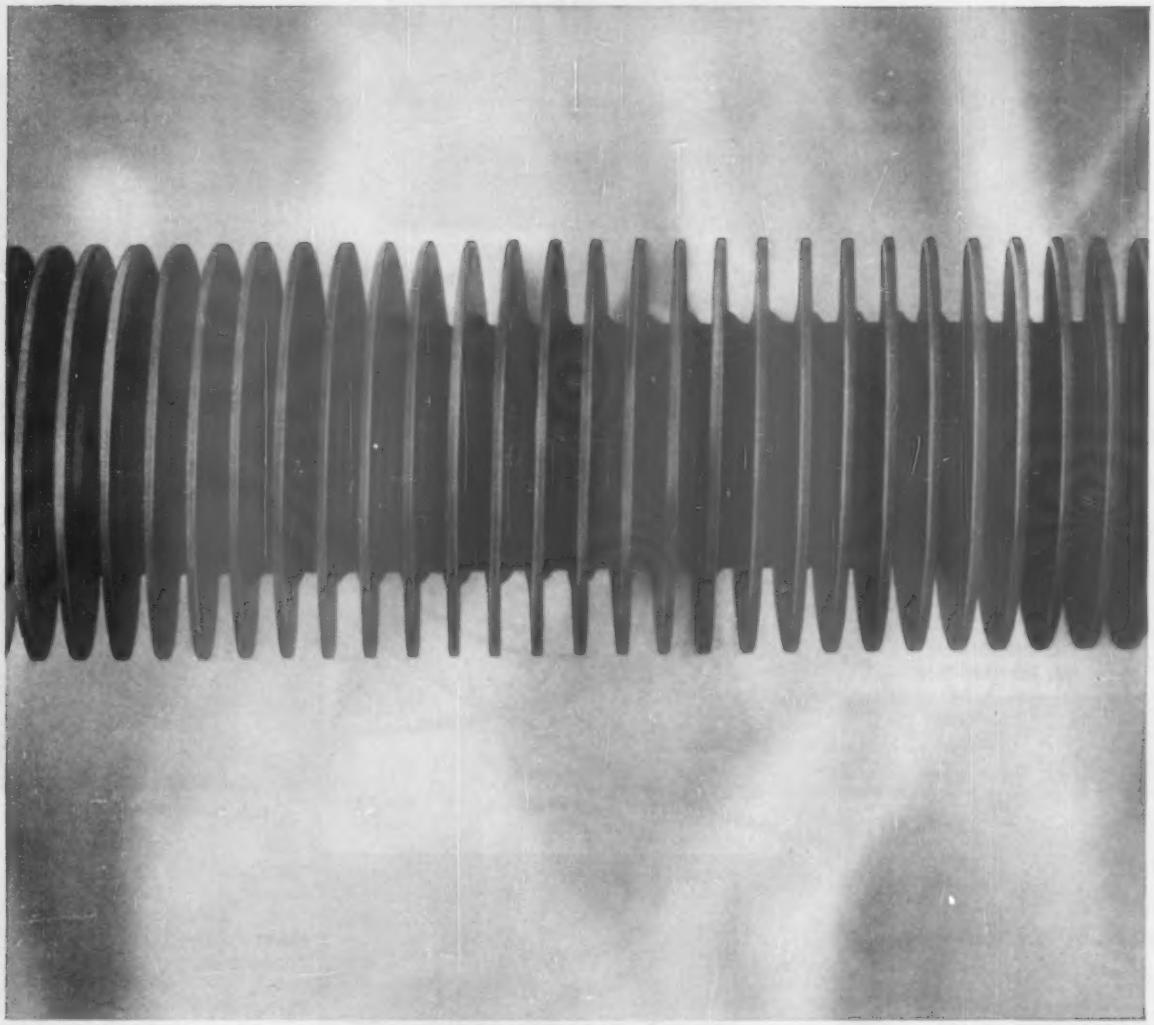

Deep-finned heat-exchanger tube developed for the British nuclear power stations.

The know-how on gas-cooled reactors

Only a year or two ago, a gas-cooled, graphite-moderated reactor was considered, by many people, an unpromising stop-gap as a power generator. It has, however, proved to be capable of such rapid development that in Britain the 1965 target for atomic power generation has been stepped up from 2,000,000 kW to 6,000,000 kW with very little increase in the number of stations.

Calder Hall, designed in 1953, develops 70,000 kW. By the time it became critical in 1956, 300,000 kW stations were coming off the drawing board. The latest station at Hinkley Point will have an electrical output of 500,000 kW.

This surprising advance is the result of knowledge gained during the structure and operation of Calder Hall: it is largely a matter of straightforward engineering development in which the companies of Tube Investments Limited have played an important part. Their know-how goes into components for the new stations but it is also available to assist all engineering firms engaged in atomic power production. And so are the components—such as this deep-finned heat-exchanger tube—designed and made by a T.I. Company.

Other products include:—Fuel element cans · Rare metal components · Engineered reactor components such as:—Control rod, graphite restraint and stand pipe assemblies · Neutron sources.

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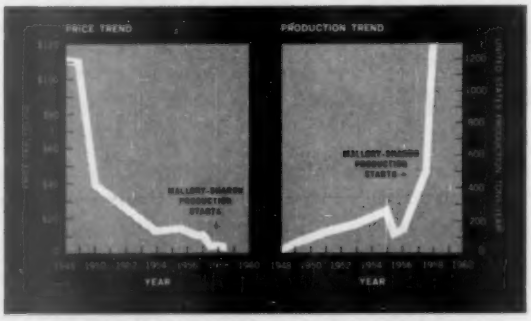

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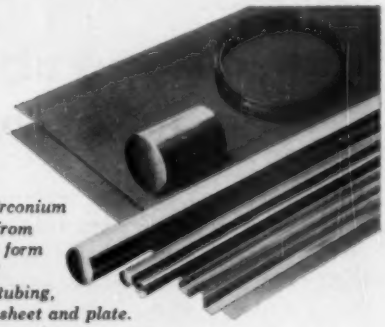

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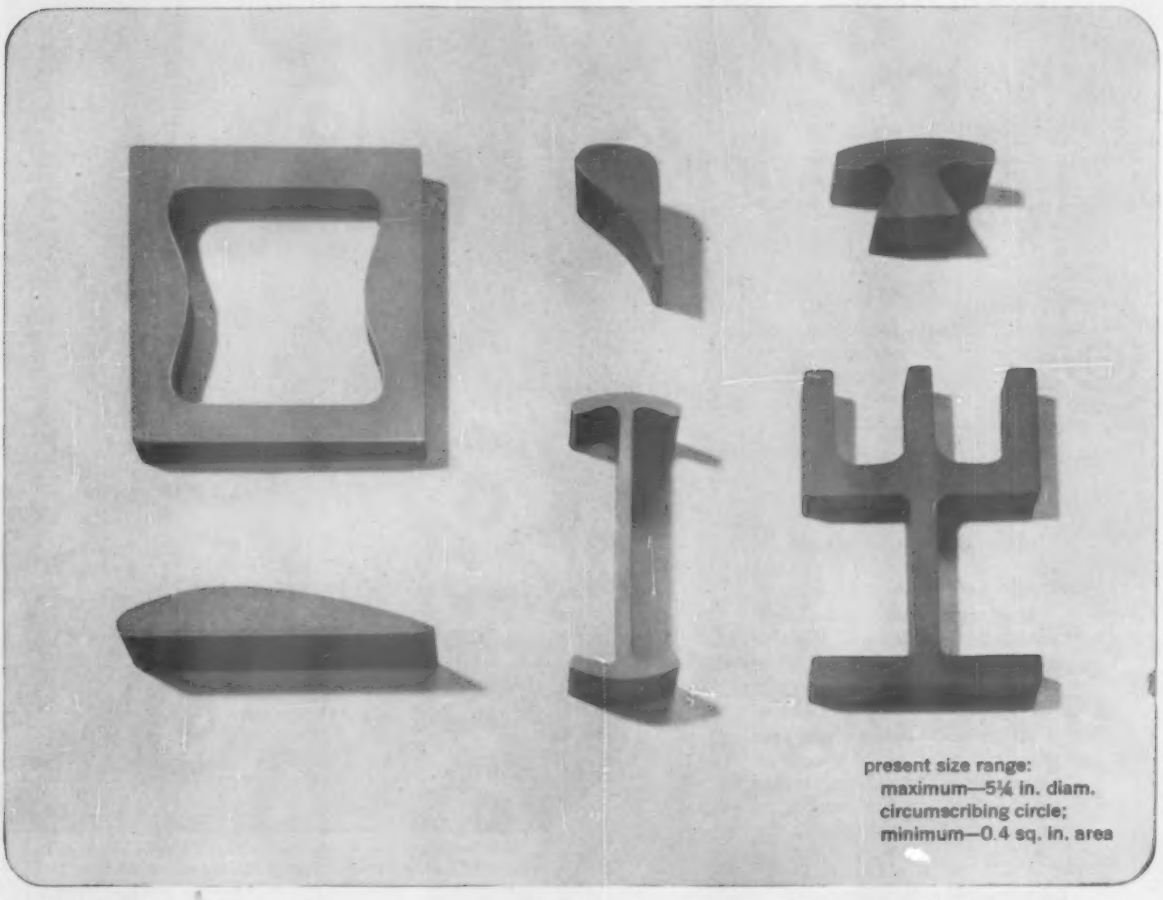

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- 405 Stainless
- SAE 1020
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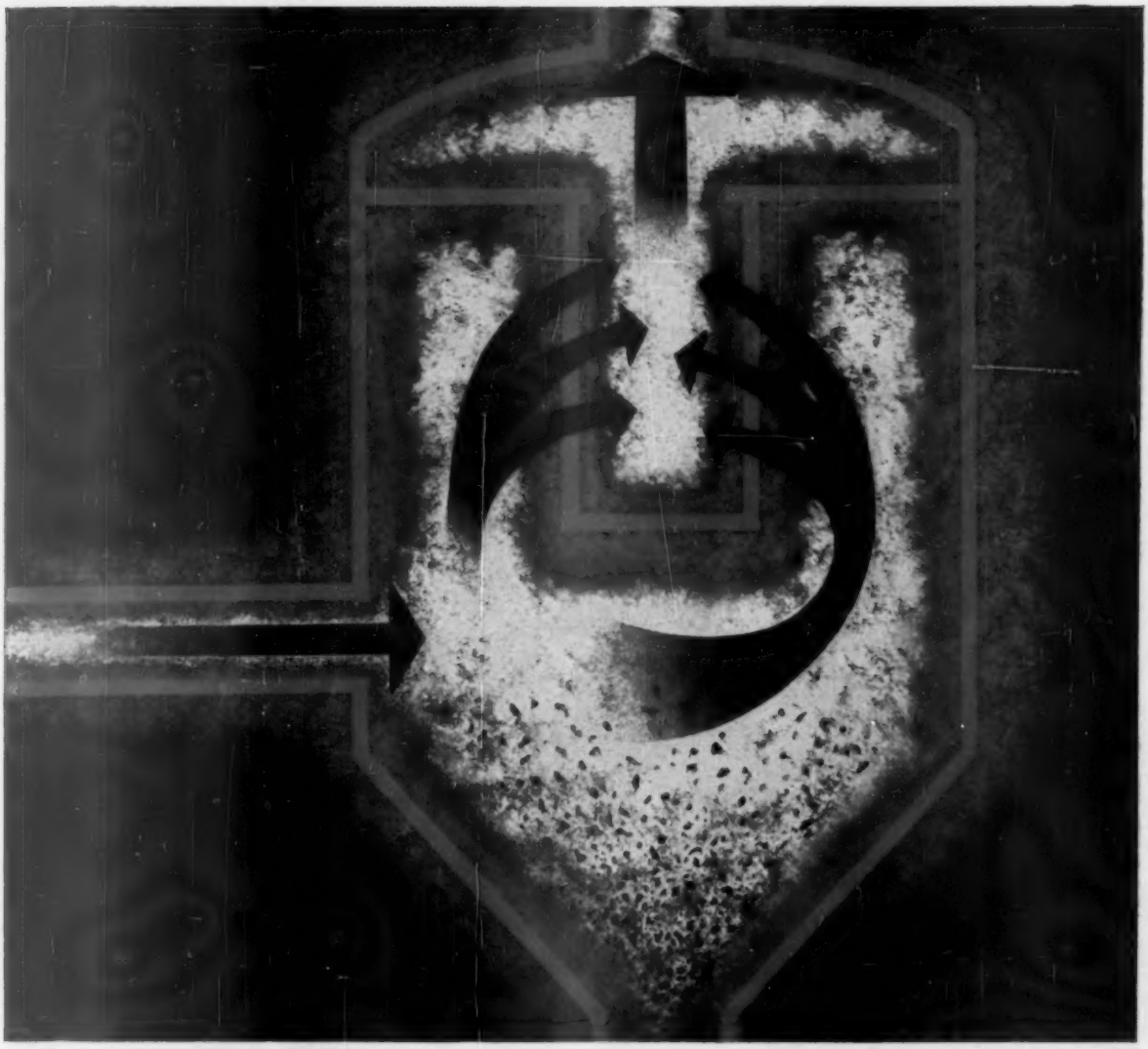

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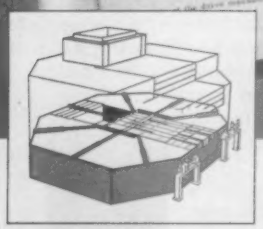

The AMF-GNE Educator designed by Dr. Walter H. Zinn's General Nuclear Engineering Corporation.

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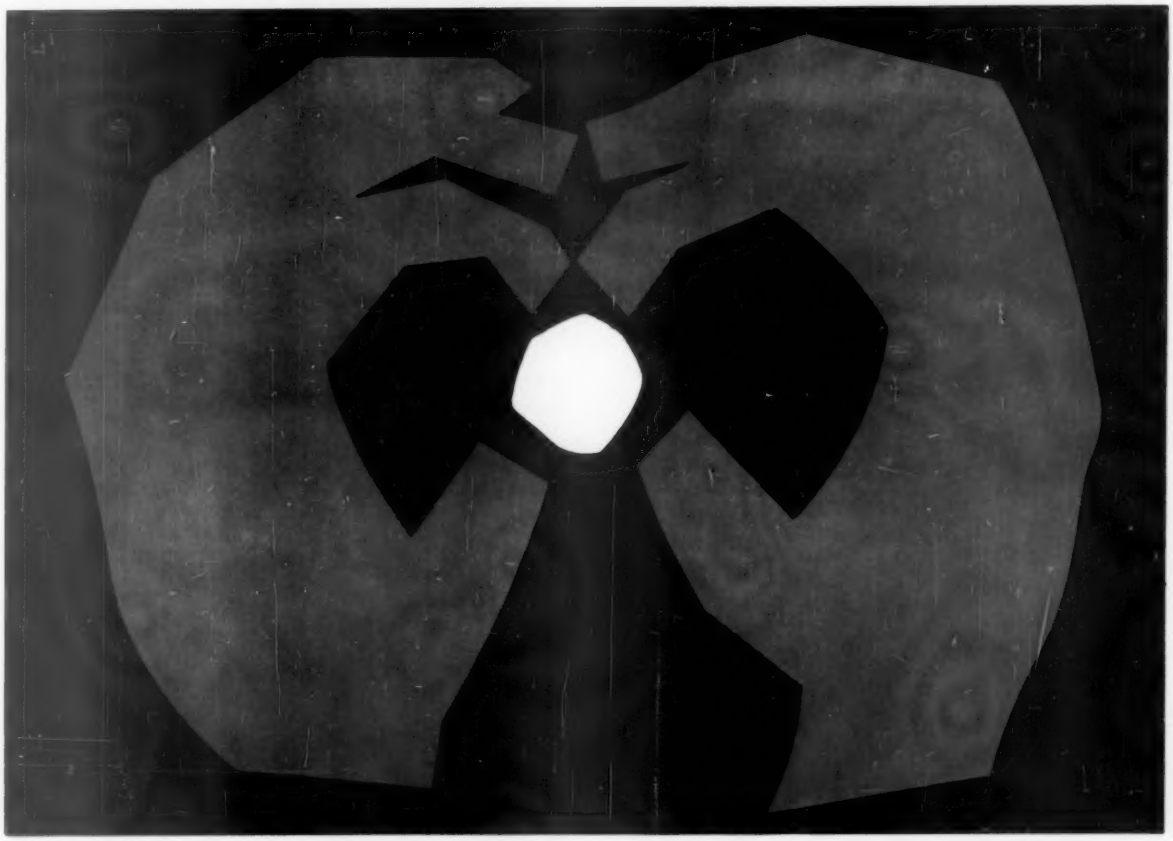
Another example of AMF Atomics experience at work

AMF ATOMICS



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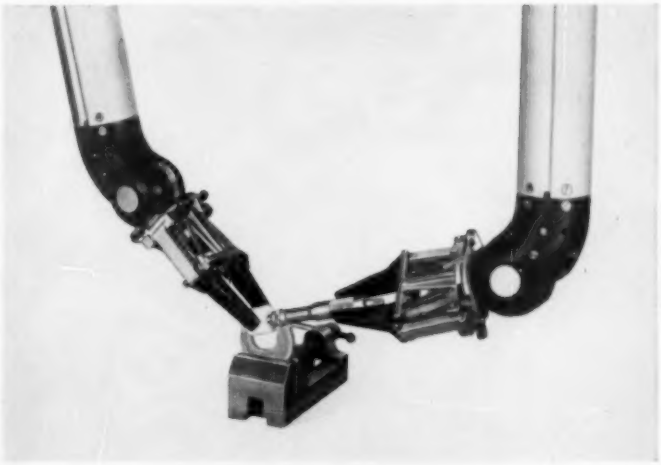

Central Research Manipulators from basic Argonne National Laboratory design

Central Research
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Why cyclotron magnet frames are made from forgings

Man is in a desperate race to learn more about magnetics. One famous acres-big cyclotron could be reduced to the size of a steamer trunk if they could only find a way to increase the magnetic field strength by 20 times. And already we see evidence that very strong magnetic fields may hold the secret to one of man's most sought-after dreams: sustained nuclear fusion power generation.

But when you double the strength of a magnetic field, the energy density or pressure increases *fourfold*. A not-uncommon 50,000 gauss magnetic field exerts a pressure of about 1,400 psi; but other laboratory experiments have already created fields of 1½ million gauss for a few microseconds, and they confidently expect to hit *10 million* gauss before long!

To contain the fantastic forces, designers of very large electromagnets turn to high-quality forged steel parts, and they very often come to United States Steel to ask for USS Quality Forgings.

The picture shows a cyclotron electromagnet frame that will go into service at Oak Ridge National Laboratory, Oak Ridge, Tennessee. It is made from six USS Quality Forgings that total 193 tons including the two cylindrical pole pieces. The pole pieces are machined to a .005″ flatness, and are parallel to within .005″. These tolerances are essential for close control over the bombarding particle beam—which often operates at velocities which approach 50,000 miles *per second*. All six forgings were melted, forged, machined, heat-treated and inspected right at our Homestead Forgings Division, and we also furnished all dowels (4½″ in diameter), nuts, bolts and lifting eyes.

Many cyclotron and nuclear reactor parts are made from USS Quality Forgings because buyers have learned that they are made from the finest steel, on the most modern equipment, by the most skilled forging men in all the world. No matter what kind or size of USS Quality Forgings you buy, you get the advantage of these same facilities. Please address inquiries or requests for our free forgings booklet to United States Steel, 525 William Penn Place, Pittsburgh 30, Pa.

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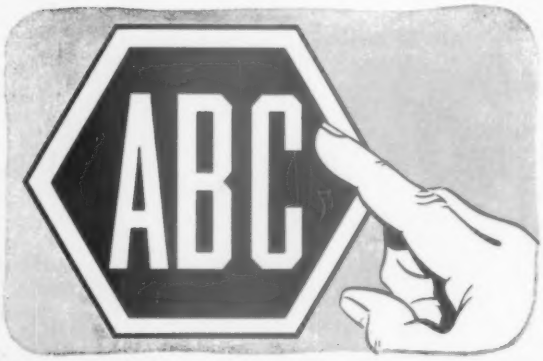

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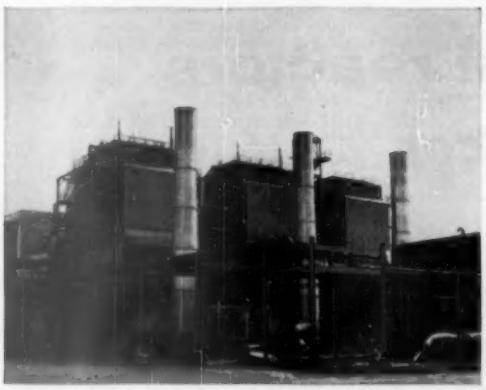

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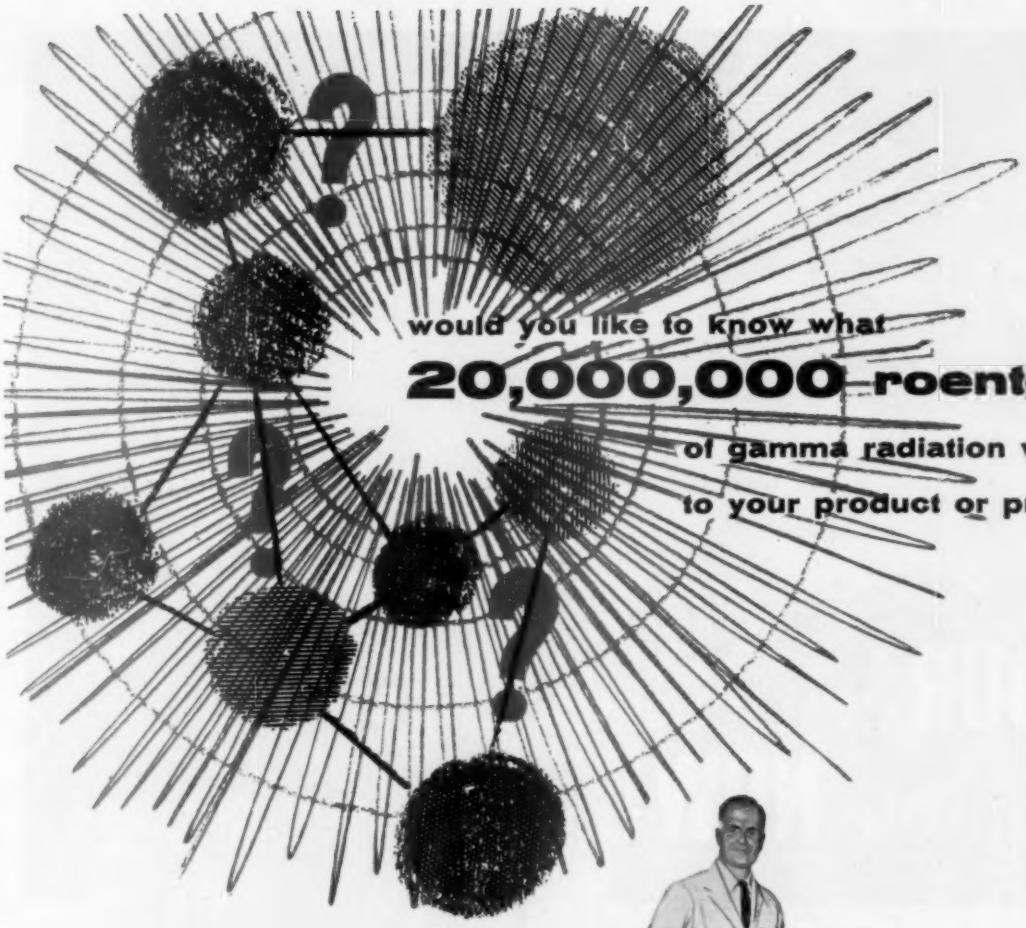

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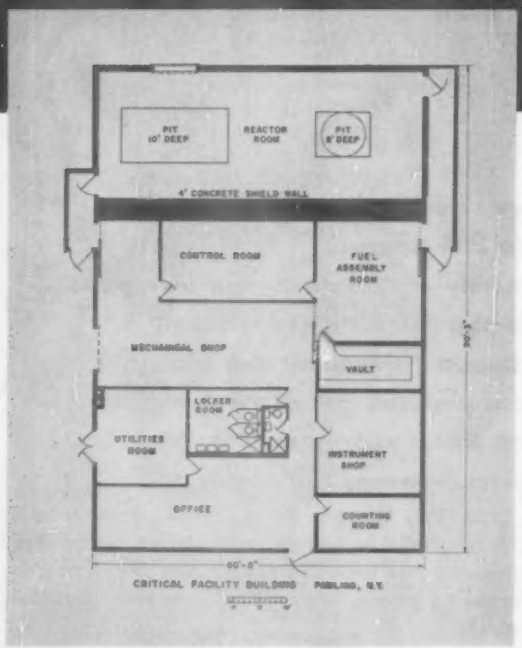

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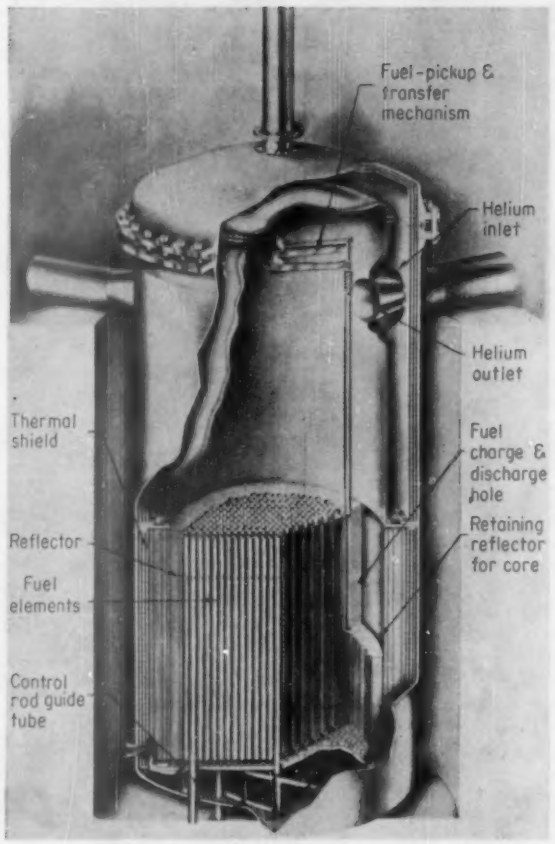
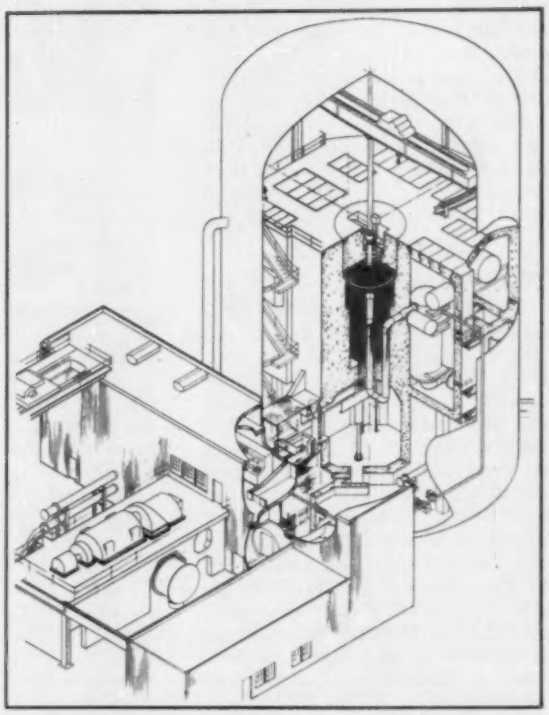




The General Atomic–HTRDA Reactor: Cutaway of reactor vessel (left) shows second core of the helium-cooled unit with its graphite-clad moderator-fuel elements of compacted carbides of uranium and thorium with graphite. Conceptual view of entire plant is shown above.

51 Utilities Back Alternative to AEC-JCAE Gas Reactor

Fifty-one private utility companies joined forces last month to try to head off the impending federal construction of this country's first commercial-type, gas-cooled reactor.

Their proposal to build a 30–40-Mw(e), high-temperature, helium-cooled and graphite-moderated reactor on the grid of the Philadelphia Electric Co. represented the private utility industry's answer to a challenge of the Joint Committee on Atomic Energy. JCAE, which has been insisting for more than two years that the U. S. reactor program should include a gas-cooled type, had directed AEC to build a gas reactor on an AEC-owned site.* The Committee only reluctantly agreed to let AEC canvass industry first for a sponsor.

The proposal is a daring one that not only accepts JCAE's challenge, but offers a counter-challenge from the private utility industry. Designed by General Atomic division of General Dynamics Corp., the reactor goes well beyond present U. S. gas-reactor designs, according to GA officials, and would put the U. S. abreast of Britain's much older gas reactor program.

The design, in fact, is so advanced that there is a real question whether the proposal can meet the Dec. 31, 1962, completion deadline set by AEC in its invitation of Sept. 22. Although the press announcement by the new group spoke of the plant's being "scheduled to be completed late in 1962 or early in 1963," the proposal as laid before AEC calls for construction to start in mid-1960 for completion by June 30, 1963, and startup by Dec. 31 of that year.

GA officials asserted that—although it could not be guaranteed—construction might be completed considerably earlier than their "realistic" June 30, 1963, estimate. In any event, they said, they hoped to convince AEC and JCAE that their reactor design justified, in the best interests of U. S. reactor capability, a possible delay in completion past AEC's Dec. 31, 1962, deadline.

GA and Philadelphia Electric officials have until Feb. 21 to convince AEC of this. If they fail, AEC must proceed to build a gas-cooled plant at one of its sites, yet to be determined. If they succeed, they must then convince JCAE, which must approve the agreement.

Uncertainty over the completion date of the HTRDA reactor would be a major issue in any JCAE review. Committee Democrats have been loud in their criticism of another reactor project of radically

* NU, Sept. '57, 23; Oct., 22; Nov., 17; July '58, 22; Aug., 17 & 118; Oct., 27; Dec., 30.

advanced design (the Pennsylvania Advanced Reactor) whose sponsors encountered delays and financial problems after having set out to do the job without AEC financial aid. Another respect in which the GA design does not meet JCAE's original criteria is on exportability: its use of fully-enriched uranium involves a material highly expensive and unlawful to export except in small quantities; helium, also, is in critically short supply (although JCAE has approved helium in the AEC's gas-cooled design).

HTRDA Is Born

The 51 operating utilities sponsoring the project have banded together in a new non-profit firm, High Temperature Reactor Development Associates. Their $39-million proposal contemplates that the Bechtel Corp. would build the plant on the Philadelphia Electric system for $24.5-million on a fixed-price, turnkey basis, provided AEC agreed to contribute pre- and post-construction research and development work, to a maximum of $14.5-million, under contract with General Atomic. Philadelphia Electric's proposed site is reported to be in southern Delaware or Chester counties of Pennsylvania.

GA would be responsible for the nuclear portion of the plant, under a fixed-price contract with Bechtel; Westinghouse would be responsible for the turbine-generator system. Philadelphia Electric would pay $8-million toward construction, and HTRDA would pay $16.5-million from contributions of 0.1–0.5% each of their annual gross billings for five years. Philadelphia Electric is contributing the site.

Until now, the largest utility groups for nuclear power had been the 31-utility Atomic Power Development Associates and the 18-utility Power Reactor Development Corp.

Design Summary (Second Core)

Electric power, net	40 Mw
Thermal power	115 Mw
Helium inlet temp.	662° F
Helium outlet temp.	1382° F
Total He flow at nominal power	440,000 lb/hr
Steam at turbine	1450 psig, 1000° F
Steam flow at nominal full power	367,000 lb/hr
Thermal efficiency, gross	37%
Fuel element lifetime at 80% load factor	3 yr

Balancing this, however, a quick NUCLEONICS check showed that of the 51 HTRDA companies, 44 already belonged to one or another existing reactor project group.

Some industry leaders expressed fear that the very size of the group might evoke charges from the public power lobby that this massive mobilization of private power companies was essentially no more than a political maneuver. Yet there seemed to be no question in the minds even of private-power leaders that political motivation had a great deal to do with the formation of HTRDA. In fact, it was used as a sales argument. Utility firms were told, as one official put it:

"Industry has got to get off the dime and do something more than talk. Somebody has got to build this plant, or at least make an offer to, or the Joint Committee will just sit back and say, 'We told you private industry couldn't do the job; the government will have to do it.'"

The HTRDA proposal was the only one filed in response to AEC's invitation. Should it be rejected by AEC or JCAE, the leading candidate to build the gas-cooled reactor for AEC would be the ACF Industries–Kaiser team, which has been doing design work on a 35-Mw(e) unit, also He-cooled and graphite-moderated, for a year (NU, Aug. '58, 118).

The head of steam GA and Bechtel were able to build up behind their project was such that when Southern California Edison, which was to have played the key utility role of accepting the station on its own grid, dropped out of that position just days before the bid was to go in, another major utility was found to step in and take its place. Philadelphia Electric, the nation's seventh biggest utility in terms of peak load, with 2.28-million kilowatts installed, is already a member of both APDA and PRDC.

The Technical Side

The reactor's first core, it is contemplated, would have metal-clad fuel elements containing homogeneous carbon compacts of fully-enriched uranium carbide and thorium carbide, and would produce only 30-Mw(e), from 850° F, 850 psi steam. Coolant would enter the core at 582° F, leaving at 1015° F. By the time of insertion of the second core, GA expects to have ready all-ceramic fuel elements: homogeneous carbon compacts containing carbides of U^{235} and thorium nested in long impervious graphite tubes. These would substantially raise the temperature ceiling while eliminating loss of neutrons to absorption in metal cladding, and thereby would raise power output, to 40 Mw(e).

GA plans to carry out research and development simultaneously on these two cores, and holds out hope that the second core may progress so fast that the metal-clad one "may never have to be installed." Techniques for first-core element fabrication need not be perfected until 1962, they pointed out.

Principal designer of this reactor for GA was Peter Fortescue, chief planner of Britain's HTGCR (High Temperature Gas Cooled Reactor, NU, Sept. '58, 79), whom GA hired away from the U. K. Atomic Energy Authority just a year ago (NU, Dec. '58, 108). GA itself has been working on the fuel body for such a reactor for two years.

HTRDA Member Utilities

Alabama Power Co., Birmingham
Arizona Public Service Co., Phoenix
Atlantic City Electric Co., Atlantic City, N. J.
Baltimore Gas & Electric Co., Baltimore, Md.
California Electric Power Co., Riverside
Central Illinois Electric & Gas Co., Rockford
Central Illinois Light Co., Peoria
Central Illinois Public Service Co., Springfield
Central & South West Corp., Wilmington, Del.
—*controlling:*
Central Power & Light Co., Corpus Christi, Tex.
Public Service Co. of Oklahoma, Tulsa
Southwestern Power Co., Shreveport, La.
West Texas Utilities Co., Abilene
Central Louisiana Electric Co., Alexandria
Cincinnati Gas & Electric Co., Cincinnati, Ohio
Cleveland Electric Illuminating Co., Cleveland, Ohio
Delaware Power & Light Co., Wilmington
Detroit Edison Co., Detroit, Mich.
Gulf Power Co., Pensacola, Fla.
Gulf States Utilities, Beaumont, Tex.
Hawaiian Electric Ltd., Honolulu
Idaho Power Co., Boise
Illinois Power Co., Decatur
Iowa Public Service Co., Sioux City
Kansas City Power & Light Co., Kansas City, Mo.
Kansas Power & Light Co., Topeka
Kentucky Utilities Co., Lexington
Middle South Utilities Inc., New York—*controlling:*
Arkansas Power & Light Co., Little Rock
Louisiana Power & Light Co., New Orleans
Mississippi Power & Light Co., Jackson
New Orleans Public Service Inc., New Orleans
Mississippi Power Co., Gulfport
Missouri Public Service Co., Raytown
Montana Power Co., Butte
New York State Electric & Gas Corp., Binghamton
Niagara Mohawk Power Corp., Syracuse, N. Y.
Pacific Gas & Electric Co., San Francisco
Pacific Power & Light Co., Portland, Ore.
Pennsylvania Power & Light Co., Allentown
Philadelphia Electric Co., Philadelphia
Portland General Electric Co., Portland, Ore.
Public Service Electric & Gas Co., Newark, N. J.
Public Service Co. of Colorado, Denver
Public Service Co. of New Mexico, Albuquerque
Puget Sound Power & Light Co., Bellevue, Wash.
Rochester Gas & Electric Corp., Rochester, N. Y.
St. Joseph Light & Power Co., St. Joseph, Mo.
San Diego Gas & Electric Co., San Diego, Calif.
Sierra Pacific Power Co., Reno, Nev.
Southern California Edison Co., Los Angeles
Utah Power & Light Co., Salt Lake City
Washington Water Power Co., Spokane

Some of the many problems GA's research and development program must solve, NUCLEONICS learned, are these: getting a graphite with sufficient porosity so that fission-product gases do not build up pressures weakening structural integrity; developing appropriate graphite-fabricating and -compressing techniques; learning the chemistry of U and Th carbides; determining compatibility, for the first core, of metals with graphite under thermal cycling (austenitic and type-430 stainless steels and niobium are possibilities); determining how pure the helium has to be; building mockups to measure heat-transfer coefficients; arriving at a detailed understanding of the flux distributions and the related power distributions; establishing the conversion ratio and temperature coefficient; carrying out an extensive calculating program on reactor control; developing needed hardware such as helium blowers.

Specimen fuel compacts have already been irradiated in the Materials Testing Reactor in Idaho.

General Atomic claims these six advantages for its new design: simplicity and compactness; use of inexpensive construction materials with resultant lowering of costs, particularly in larger plants; modern steam conditions and high thermodynamic efficiency; low fuel-cycle costs due to high burnup; good nuclear economy; "an extraordinary degree of inherent safety." The GA proposal said a 325-Mw(e) scaleup of this design would be competitive "in many areas of the U. S.," because of "the increased efficiency of the graphite moderator in larger core sizes: hence, the potentially long fuel burnups, low fuel-cycle costs, and relative insensitivity to fuel reprocessing charges can be realized at the higher power levels."

The graphite-canned fuel-moderator elements would be operated, GA said, at temperatures that give adequate heat transfer by radiation from the graphite-uranium-thorium compacts to their graphite "cans."

A unique safety feature claimed for the system is its ability to absorb shutdown heat even in case of loss of coolant. The side and bottom graphite reflectors normally work at the inlet temperature and thus form a built-in heat sink to which the core can radiate heat in an emergency. Additional safety is provided by the homogeneous fuel-moderator mixture which insures a prompt-acting negative temperature coefficient.

Give IAEA Controls Or It Will Die—Cole

Sterling Cole dropped diplomatic circumlocution last month and swung from the hip in a vigorous attempt to succor his becalmed International Atomic Energy Agency. Candidly, the director-general of IAEA told the Atomic Industrial Forum that "nearly three-quarters of the countries of the world today are accommodated by way of bilateral agreements," and "if the needs of those countries are to be filled by bilateral routes, then there is no need for the existence of this Agency."

Although his remarks were interpreted as being directed against U. S. policy, he emphasized that he had equally in mind "the atomic countries" that have been writing bilateral treaties—the U. S. S. R., U. K. and U. S. In fact he told NUCLEONICS later that he felt the U. S. less remiss because it was the only one that did make specific reference in bilaterals to IAEA, in its more recent pacts with Euratom and Japan.

"As I see it," Cole told the Forum, "the full goal that this Agency was conceived to reach will not be reached if the atomic countries of the world insist on implementing and carrying out continuously and indefinitely their bilateral agreements. Because the good part, the golden, glittering part, of atomic energy can be accomplished by some subsidiary arm of the U. N. as a technical assistance operation. . . It is true that it would be more effectively carried out by a separate organization such as this, but the administrative costs of conducting an agency purely for technical assistance . . . [are] too great, in my personal judgment, for the continuance of such an agency."

Problem of Prices

A second problem Cole pleaded with his audience to give some attention to, in connection with Agency purchase and sale prices for fissionable material, is "that some formula be devised by which customers of the Agency can have a bit of a preference." He recalled that the Soviet Union offered its U^{235} at "the lowest world price" without naming a figure, and that the U. S. —whose offer is frequently mistaken for, but is not in fact, a gift—likewise has given no firm indication of the price it will charge the Agency for U^{235} allocated to it (U. S. law says it cannot be sold abroad at a price below the domestic price).

"Unless some preferential terms are given to the Agency, to Agency customers," Cole declared, "purchasing countries will—unless they have some political reason for doing otherwise—will come directly to the U. S. for their material, because they can get it directly from the U. S. on terms equally good, and perhaps even cheaper, than they could get from the Agency."

Preferential terms would also permit IAEA to develop a fund by charging a bit more than it pays to the U. S., Cole said. Such a fund would relieve IAEA of depending on voluntary U. S. aid, and could be used to pay the costs of international control.

"A decision should be made fairly early that these bilaterals will all be put under the Agency to avoid creating a pattern which will make it more difficult to turn them over to the Agency at a later stage," he said in an interview. "It should be firmly established that supervision of those power reactors [provided for under power bilaterals] should be done by the Agency . . .

"It is too late to do anything by way of firm contractual obligations. The way is open to do it by diplomatic persuasion."

Washington Reaction

NUCLEONICS found official Washington largely unperturbed by Cole's speech. There seemed to be no evidence of any intention to take decisive action to terminate bilaterals or fold them into IAEA.

Cole—who emphasized again and again in his talk that he spoke not as Agency director-general but as an individual—listed the positive achievements and projects of the Agency.

- Development of a code for safe handling of isotopes, covering packaging, transport, use and disposal, was initiated in January and completed in August.
- About 200 students have already been sent to schools throughout the world under the training program; a doubling of funds for next year is requested.
- A panel will shortly begin a study of the scientific aspects of waste disposal in the sea. Another, a legal experts' group, will develop recommendations on the third-party liability question. A third study soon to be undertaken is on the transport of irradiated fuels.

JCAE Faces Heavy Legislative Schedule in 1959; Acceleration, Euratom, Patents Among Major Issues

Sen. Clinton P. Anderson, chairman-designate of the 86th Congress' Joint Committee on Atomic Energy, will convene his committee early next month to lay out a legislative program for 1959. It promises to be the most extensive and important since adoption of the Atomic Energy Act of 1954.

At the top of the list, of course, is acceleration of civilian power reactor development under a long-range program; this issue will arise immediately after Congress convenes —at a multi-day, closed-door symposium of JCAE with industry. Other JCAE agenda items:

- A comprehensive investigation of the U. S.-Euratom reactor and research agreement and—later in the session—JCAE review of reactor projects under the agreement. The bilateral will go to JCAE in January.
- A re-appraisal of the controversial patent provisions of the 1954 Act, brought on by expiration on Aug. 31, 1959, of the Act's compulsory-licensing provisions (*see page 27*).
- Another look—more exhaustive than last year's—at the Administration's plutonium-production and -purchase policies.
- Consideration of a cooperative AEC-industry program for development of a nuclear merchant marine. The House Merchant Marine Committee and the Senate Interstate and Foreign Commerce Committee have jurisdiction over merchant marine matters and there is still a question as to how this program will be considered by Congress.
- The first JCAE inquiry into federal-state relations and workmen's compensation in the nuclear field, as well as waste disposal.
- Such routine, but often critical, chores as authorization of AEC's plant-and-equipment program for fiscal 1960 and consideration of AEC-sponsored legislation (patent amendments and a draft bill permitting AEC-industry cooperation on peaceful uses of nuclear weapons are among those under preparation).

JCAE '59 Calendar

Euratom—mid-Jan.
Waste Disposal—late Jan.
Annual '202' Hearings—mid-Feb.
Acceleration
Long-Range Program
Workmen's Compensation—March
Patents—April
Federal-State Relations—May
Plutonium Price and Production
Merchant Ship Program

Acceleration

Until AEC Chairman John A. McCone came on the scene last summer, AEC and JCAE were in agreement that acceleration was a must—primarily for foreign-policy reasons, and in near-agreement on a long-range program aimed at assuring economic nuclear power by the late '60's; action on a program was put off until 1959, primarily because agreement came too late in the 1958 session. It was apparent that AEC had acceded to congressional-industry demands for a long-range, accelerated program and that the way was clear for action.

McCone, however, not bound by the policy decisions of a Commission which he did not chair, has ordered a unilateral AEC review of the U. S. reactor development effort. A new program paper, which may or may not look like the AEC paper presented to Congress in June, will be drawn up with the help of an ad hoc committee on reactor policies (NU, Nov. '58, 25).

Under the chairmanship of Assistant AEC General Manager Alfonso Tammaro and the vice-chairmanship of former Commissioner Henry D. Smyth of Princeton Univ., the ad hoc group is conducting a series of closed hearings to take testimony from reactor manufacturers, utility officials and others with a special interest in reactor development. Committee sources said it was being "somewhat selective" in its review (giving more time to some concepts than to others), that it was concentrating on "getting the technical facts," and that it would disband after making its recommendations—probably in January.

Stronger JCAE?

The ad hoc committee has been asked to file its report in sufficient time to permit the Commission to study it before making its annual "202" state-of-the-atom report.

When Chairman McCone leads the AEC contingent up to Capital Hill for these hearings, he will face a Democratic-dominated JCAE that appears to hold its strongest position since 1954. This is not so much a result of a change in faces on the Committee as much as it is a result of the November elections. The Democratic sweep gave the party a majority of 131 seats in the House and 30 in the Senate, as compared with respective margins of 35 and 2 in the 85th Congress.

Although the Democratic landslide does not affect the 10–8 ratio of Democrats-to-Republicans on the Joint Committee, it does give the Democratic majority some reserve power in the House and Senate if it finds itself forced—as it was on the Gore-Holifield bill of 1956—to proceed with acceleration or other

AEC sets up fourth round?

Acting under Congressional mandate, AEC last month took complete control over the choice and scheduling of federally-aided reactors built under the third round of the Power Demonstration Reactor Program—and, in effect, set up a new fourth round. Language added in this year's authorization bill by the Joint Committee (NU, July '58, 22), AEC said, requires it to select all P.D.R.P. reactors; to invite industry to take on the projects with AEC help; to build any reactor on which industry fails to make an acceptable proposal; and to set deadlines for accepting and negotiating industry proposals. New construction deadline for all P.D.R.P. reactors is June 30, 1964. The first invitation under the new program, AEC officials said, is expected to go out within the next few weeks, to permit replies and negotiation thereon by June 30, new deadline for AEC approval of third-round proposals. The invitation, which offers the same aid as the original third-round call, will probably cover process heat reactors, though others are under study. As in the gas reactor invitation (*see p. 17*), 60 days is expected to be allowed for replies, 90 days for negotiation.

controversial proposals against Administration opposition.

Despite their large majorities in Congress, however, the JCAE Democrats still hope for a bipartisan program on acceleration. From a practical standpoint, AEC-JCAE agreement avoids the Presidential veto problem and assures the harmony that is so crucial to both domestic and foreign policies on the atom.

Johnson for Merchant A-Fleet

Support for acceleration came from an unexpected, but powerful, source only three days after the Congressional election: Sen. Lyndon Johnson, Democratic majority leader in the Senate and chairman of the Senate Democratic Policy Committee. In a speech at Big Springs, Tex., Johnson listed 12 major issues which the 86th Congress "must face up to"—second among them an expanded program on atomic energy.

"Our [present] atomic activity is impressive," he agreed. "But it is only in its infancy. The atom holds out to us the promise of greater immunity from disease, greater power to do the heavy work of the world; and perhaps even the motive force for touring the universe itself . . .

"We need a program to develop the peaceful uses of the atom—with emphasis on an atomic merchant marine."

Johnson's surprising demand for a nuclear merchant-ship program was explained by government officials this way: The government's annual bill for subsidizing the U. S.-flag merchant marine in fiscal year 1960 will near $500-million, and it continues to rise. Nuclear propulsion—possibly permitting U. S. vessels to approach the lower operating costs of foreign-flag ships and thereby cutting federal subsidies—offers the best course for holding down subsidy expenses.

For this and political reasons (U. S. leadership in nuclear propulsion), Johnson, JCAE Chairman Anderson, Maritime Administrator Clarence Morse and Congressional spokesmen for the merchant marine industry are pressing for a cooperative ship demonstration program as outlined in October by Morse (NU, Nov. '58, 27).

A bill spelling out the program's ground rules has been drafted by the Administration and is expected to be introduced early in the 1959 session. It calls for an industry-government approach paralleling that of AEC's reactor demonstration program and provides for government aid, where necessary, in research and development, construction and operation.

When and if the program is successful in helping the merchant marine to economic ship operation with nuclear power, the government would withdraw all but usual subsidy aid for merchant vessels.

Floberg, Sporn, Lindseth Speak Out on Future

Interesting contributions to the reactor acceleration debate came last month from AEC Commissioner John F. Floberg, from Edison Electric Institute President Elmer Lindseth, and from Philip Sporn, president, American Electric Power Co. The first spoke at the Atomic Industrial Forum's annual-meeting banquet in Washington; the last two filed views with JCAE.

Floberg's keynote: "I think it is important that we be realistic about the future potential of the atomic energy industry. . . . It is only a matter of time before nuclear power will stimulate very substantial amounts of technological and economic activity. In the interim period before that comes to pass, however, there may well be periods when there will be difficulty in keeping everybody busy who would like to be busy."

Lindseth's keynote (as chairman of the EEI Committee on Atomic Power), in response to a JCAE invitation to comment on a "proposed expanded civilian nuclear power program" (NU, Sept. '58, 155): "[Any such program] should be so conceived and administered as to maximize participation in and ownership of facilities by private enterprise and thereby assure that normal business incentives and the nation's normal business system will at the earliest practicable date replace government control, direction and ownership."

Sporn's keynote: ". . . the attempt to develop a statement now of a 'proposed expanded civilian nuclear power program' impresses me as a sound idea. . . . But I believe such a program needs to be formulated in provisional terms having definiteness for only two or three years forward with machinery for continuous study and examination to enable the Congress and AEC each year to lay a solid basis for projection forward for another year."

Floberg Warning

Commissioner Floberg's note of caution that the next decade—before generally competitive nuclear power—may be lean, fell on an industry audience which was generally at its most optimistic in two years.

"It is possible . . . that this industry, at least insofar as concerns the program to achieve the short-range goal of competitive nuclear power," Floberg suggested, "has now reached that stage in its normal development when the number of basic new concepts which [it] may be justified in exploring may be tapering off. . . .

"The work of the near future may well be that of engineering improvement of the few basic concepts now well-defined rather than any ever-expanding program based on new combinations of moderator, coolant, fuel, blankets, etc."

Lindseth on Philosophy

Speaking for the EEI, Lindseth took heated issue with a major point of the program paper circulated by the JCAE staff; that is, the suggestion that AEC take responsibility for building reactor prototypes, as well as the reactor experiments it is building under present policy.

"If the AEC is to be charged with the responsibility of designating the type, size and design of projects to be supported under the power demonstration program—other than in 'exceptional cases'—then industry will for the most part be deprived of the vitally needed initiative to develop promising reactor types."

Sporn Adds:

Sporn made three over-all points: 1. the government should set up a permanent reactor advisory committee to conduct a continuing reappraisal of the reactor program and suggest changes and additions; 2. research-development aid should be granted on new concepts on a 50-50, government-industry basis, with no industry commitment to build a reactor if development work on the concept is negative; and 3. capital subsidies should be available—the major portion of the difference between cost of a nuclear and conventional power plant.

Proposed Ground Rules for U. S.-Euratom Program

The first specific details of what implementation of the U. S.-Euratom agreement will mean to the American nuclear industry was outlined in Washington last month at the Atomic Industrial Forum annual meeting.

Allen J. Vander Weyden, new deputy director, and Nelson F. Sievering Jr., new assistant director of AEC's Division of Reactor Development, reported on the first flesh hung on the bare bones of the U. S.-Euratom bilateral (NU, June '58, 17): this is the proposed set of criteria, worked out in Washington in October by a U. S.-Euratom working party, to govern administration of the joint **research-development program** and the **selection of reactor projects** for the joint one-million-kilowatt power program.

Here are the proposed ground rules, as sketched out broadly at the Forum meeting. Not yet ratified, they are subject to change.

RESEARCH AND DEVELOPMENT PROGRAM

Scope: To be established for 10 years; level of expenditure for first five years $50-million by U. S. and $50-million by Euratom. Focus is to be strongly oriented toward specific reactor types to be built in one-million-kilowatt power program; if latter is to be successful, it's felt, an energetic research-development effort *prior to, during,* and *after* construction of the reactors is essential.

Approach: Neither Euratom nor AEC intend to mastermind the detailed content of the research-development program; but rather to solicit proposals, and evaluate them in the light of work already underway and in terms of the over-all requirements of the program. Thus industry suggestions will play a major role in program formulation since companies engaged in atomic energy work are felt to be uniquely qualified to propose areas of research that should be pursued.

Bid invitations and contracts: As soon as the requisite approvals are obtained, AEC will issue an invitation or rather a *guide* for submission of research and development proposals. It hopes to do this before Jan. 1. This should enable it to receive, evaluate and select proposals so that contracts may be awarded immediately after the U. S.-Euratom bilateral agreement comes into effect. Review and evaluation of proposals is to be done jointly by Euratom and AEC, but negotiation, execution and administration of the contracts is to be performed by each party, on its respective side, in keeping with normal procedures and practices.

Criteria: Not dissimilar from those AEC employs in its own program:

1) Extent to which the work contributes to program objectives;
2) Cost of project;
3) Competence of staff and availability of facilities;
4) Likelihood of achieving significant results in the contract period;
5) Degree of joint financial participation.

Types of work to be supported: Will fall into two major categories:

1) Projects closely allied to one of the reactors or types of reactors to be built under the one-million-kilowatt program;
2) Projects of a somewhat general nature where the work is not tied to any one specific reactor. Until selection of the reactor projects, research-development funds will be spent only for the second category of projects, as for example: behavior of UO_2 at high burnup, cheaper fabrication of UO_2 elements, preparation of cermet-type fuel elements, radiochemistry of organic moderator materials, thermodynamic properties of U-Th base alloys, systematic study of materials specifications for reactor components, etc.

In considering research-development proposals prior to submission of reactor-project and fuel-supply proposals, AEC and Euratom will try to avoid making awards that might lead to a preferential position for particular manufacturers. Conversely, firms submitting reactor or fuel proposals will have to specify what research and development *they* intend to perform in support of their proposals, to assure that this work is not paid for by the joint programs' research-development funds.

REACTOR PROGRAM

Basic guideposts AEC used in elaborating program:

1) It is the utility that will build, own and operate the plant, will assume risk of capital costs and many of risks of cost of operation. The joint program merely provides a framework with incentives to assure that the utilities move ahead.

2) The program should foster and facilitate, as far as possible within program objectives, normal commercial supplier-purchaser relationships.

3) Terms and conditions should be defined as specifically as possible, so program can move ahead rapidly with minimum of uncertainty. AEC plans to discuss and obtain industry's views before program is frozen, particularly recognizes need for such consultation on fuel element guarantees.

Timing: AEC hopes to put invitation and requirements for participation before industry provisionally as early as possible so that planning and development of proposals can begin even before invitation is issued.

Formal invitation (which must await coming into force of the bilateral) can probably be issued by March 1959. Since specific authorization and appropriation by Congress is necessary, closing date of Sept. 1 for submittal of proposals seems indicated, allowing six months for filing. This would permit AEC and Euratom to evaluate proposals and make their decisions by December 1959, obtain requisite authorizations early in 1960, and award contracts in spring 1960.

The above would be the schedule under normal circumstances. But since some proposals may be able to move on a faster schedule, and since it is desired to encourage early submittal of such proposals in the hope of concluding contracts in 1959, AEC will accept proposals at any time up to Sept. 1, 1959.

Proposal development: The invitation will be extended by Euratom to all enterprises in the Euratom Community engaged in, or willing to engage in power production. These will solicit bids on the size power plant they want at the location they have chosen. Neither Euratom nor AEC will seek any prior approval of utilities' contemplated plans, but four conditions are set:

1) Solicitation of competitive bids;
2) A firm commitment from a manufacturer to provide the plant, contingent only on getting required governmental licenses and third-party liability protection;
3) Proposal not contingent on getting research-development aid under the joint program;
4) Reasonable assurance of completion by Dec. 31, 1963.

Criteria: Any reactor type is acceptable on which research-development has been carried to an advanced stage in the U. S. and can serve as a source of safe and reliable power. Plants of at least 150 Mw(e) are preferred, but somewhat smaller plants may be justified under certain conditions. Bids should also:

1) Contain enough information to permit an independent judgment of the technical soundness of the plant design and its potential for improvement, safety of the reactor, its economics, and financial competence of the proposer;

2) Set forth extent to which proposer desires to participate in the benefits of the program, particularly with respect to a capital loan and fuel-element guarantees.

The joint evaluation will be concerned with:

1) The extent to which the reactor is expected to approach conventional power costs at time of completion and its potential for improvement;

2) The extent to which proposal would draw on funds, materials and services available for the joint program;

3) Willingness of the operator to make his facility available for research-development studies, and the terms and conditions therefor.

Fuel element guarantees: Two distinct and separable guarantees may be available to reactor operator, at his option:

1) Reprocessing and Transportation Guarantee would provide for limiting reprocessing and transportation costs to the operator in case the elements, for certain specified reasons, failed to meet the AEC-guaranteed average irradiation level.

2) Fabrication, Reprocessing and Transportation Guarantee would also provide for adjustment of fuel fabrication costs in addition.

Guarantees would be in form of a guaranteed minimum integrity life and maximum fabrication cost, for specified types of fuel elements, and would be offered to supplement or extend manufacturers' guarantees and not in lieu of a manufacturer's guarantee. Therefore one condition of eligibility is that manufacturer must offer certain minimum guarantees on fabrication cost and integrity life.

One problem for which no satisfactory solution is yet adopted: as the total contingent liability AEC may assume under the guarantees over the first 10 years of reactor operations must not exceed $90-million, how does AEC gain reasonable assurance the contingent liability it is undertaking will fall within this limitation? Several approaches are being studied.

Two other guarantees to be included in the fuel element guarantees are:

1) The fabricator must assure AEC the guaranteed life and price he extends to the reactor operator is as favorable as any other guarantee and price offered by him for any comparable fuel element within a specified time;

2) Any AEC guarantees on second and subsequent cores are contingent on the operator having obtained competitive bids for such loadings.

Deferral of two reactors in the program for December 1965 completion will be considered after November 1959, after determination of the interest in the Euratom Community in this later schedule.

Progress on 17 U. S. Power Reactors Outlined at Forum

Steady progress and achievement on twelve power reactors under construction and five already operating for some time was reported last month in sessions that have become highlights of the Atomic Industrial Forum annual meeting.

Perhaps most newsworthy items to come out of the session were (1) the "pressure suppression" system being developed by Pacific Gas & Electric and General Electric for the Humboldt Bay reactor, a system that holds promise of providing simpler, cheaper containment and doing away with external steel vapor containers (*see box*); and (2) a first account of prolonged operation of OMRE covering ten months and documenting the high optimism issuing from Atomics International about this reactor concept.

Experience

Shippingport (AEC, Duquesne Light–Westinghouse). "The most important single aspect of the Shippingport operation is the lack of major problems . . . It was demonstrated that the reactor plant had a capability for load swinging, throughout the power range, which excelled that of a conventional boiler plant." Load-swinging tests and two 1000-hr full-power runs have demonstrated the station's ability to perform satisfactorily as either a peak-load or base-load station. Only major equipment failure not previously reported (NU, April '58, 70) was that of a reactor coolant pump, replaced with the station operating at full power on its other three loops except for the time needed to lift the failed pump, and lower the replacement pump, through the equipment hatches. Some of the reactor instrument and control equipment does "not meet normal standards," mainly equipment for activity level determination. "Some of these problems appear to be disappearing with time" as operating personnel gain experience and as manufacturers and station engineers make changes.

Sodium Reactor Experiment (AEC, Atomics International). Has performed in all tests as expected from advance engineering calculations. Recent operation has been at full power: 20-Mw(th), 5.8-Mw(e); 9.7-million kwh has been generated, more than 900 Mwd. Outlet sodium temperature has been maintained at ~900° F, making SRE hottest known operating reactor today. Experience working with a large sodium-circulating system has been valuable: it has been possible to perform all types of normal maintenance operations, including replacement of pumps, valves and other components as part of testing program. Only malfunction not previously reported (NU, Sept. '58, 74): steam generator and intermediate heat exchanger have exhibited improper temperature distributions in operation, slightly limiting plant power conversion efficiency. Orificing has improved heat exchanger performance, and other designs will be tried.

Vallecitos (General Electric). Test irradiation of Dresden prototype fuel elements started in November 1957; 14 assemblies (each of nine rods) are now in reactor, soon to be increased to 50. No defect, no weld or mechanical failure has occurred to date. One assembly has had 1700 Mwd exposure, another was operated at 110% of Dresden full-load peak heat flux to check mechanical integrity without detrimental effects. Also being tested are plate and oxide

fuels including one made by the swaging process. The reactor has operated at 900–1000 psi at all power outputs up to 30-Mw(th) with no sign of instability. Maintenance work has proved relatively simple, with radiation no problem.

Organic Moderated Reactor Experiment (AEC, Atomics International). Since January OMRE has logged over 5000 hr regular operation, reaching 900 Mwd. Standard temperatures have been: bulk coolant temperature, 600° F; maximum fuel-plate surface, 750° F—temperatures typical of those proposed for full-scale OMRs; coolant velocity was 15 fps, power level 6 Mw(th). Various concentrations of high-boiler residue or "HBR"—high-molecular-weight decomposition products of the diphenyl-terphenyl moderator-coolant—were studied, the highest to date being 41%. At this concentration and at standard temperature, reactor power was 5.3 Mw, or a reduction of 12% in heat transfer rate. The effect was reversible when HBR concentration was reduced below 37%, showing that it was due to change in coolant heat-transfer properties, not deposition of film on heat transfer surfaces. The purification system later successfully reduced HBR concentration to 8%, although not as quickly as expected.

Decomposition rate decreases with increasing concentration of decomposition products in the coolant, as expected. All evidence shows complete absence of phase separation or deposition of decomposition products on either fuel elements or any other surfaces in contact with coolant, at HBR concentrations up to at least 36%; visual examination of the insides of the reactor vessel, main pump housing and 10-in. coolant pipes has shown perfectly clean surfaces. Heat transfer characteristics of the coolant did not change under irradiation throughout the range of HBR concentrations from 12% to 36%. One unexpected and welcome result: the effect of HBR concentrations above 7% has been to keep the coolant liquid at ambient temperature, eliminating the need for preheating the system to reestablish coolant circulation after extended shutdown.

Future tests will include longer operation at 30% HBR, both at present conservative temperatures and at 700° F coolant outlet temperature; tests of additional Al-clad fuel elements, and trial of Santowax R coolant.

Instead of Containment: Pressure Suppression, by GE

The "pressure suppression" system of reactor containment, being financed by Pacific Gas & Electric Co. and developed by it together with General Electric, might make PG&E's Humboldt Bay reactor plant the first large-scale nuclear station without the familiar steel sphere or capsule container, and thereby substantially reduce its cost.

As PG&E's chief mechanical engineer, C. C. Whelchel, explained it, the reactor would be housed in a simple caisson-type structure inside a low-pressure vessel. This would be connected in turn by pipes to a large but simple and relatively inexpensive underground water tank. The water in the tank would condense steam that otherwise might escape during an unusual incident, and prevent it from generating an appreciable pressure build-up in the reactor enclosure system.

Construction Progress

Army Package Power Reactor 1a (Army, Alco). Since groundbreaking on June 4, construction has been 31% completed; the lower portion of the vapor container has been fabricated, tested and secured on its concrete foundation; the turbine foundations are in and turbine building is up. Primary system components are to be installed after the spring thaw. Construction is to be completed by spring of 1960, shakedown testing by Sept. 1960.

Carolinas-Virginia Reactor (CVN-PA-Westinghouse). Research-development began in May; detailed design is to start in mid-'59, and construction at site in 1960, for completion in June 1962.

Chugach Electric Assn. Reactor (Chugach–NDA). Phase 1 of program (to determine technical feasibility of sodium-and-water system, to determine economic potential of a natural-U scale-up, to prepare preliminary design of 10-Mw(e) pilot plant in sufficient detail to permit realistic cost estimating) is to be completed in Spring 1959. Phase 1 objectives were modified to incorporate study of a possible 200-Mw(e), natural-U fueled scale-up (*see p. 25*). By Spring 1959, $4-million will have been spent on Phase 1, the first two studies of which have yielded positive results.

Dresden Station (Commonwealth Edison–GE). Heavy concrete shielding and structural support inside sphere is nearing completion, 22,000 of 27,000 yd³ poured. Main steam drum and three of four secondary generators are installed. Reactor vessel leaves Camden, N. J., shops for site this month. Condenser erection nearing completion, turbine erection to start in February. Piping and electrical work ~50% complete; control boards in place but not yet wired. First fuel arrived on site (*see p. 25*). Construction to be completed in late 1959, loading and low-power testing in early 1960, regular operation to start in mid-1960, six months ahead of contract date.

Sheldon Station, Hallam, Neb. (Consumers Public Power Dist.–AI). Site grading completed, rail sidings and cooling tower wells being put in. Final design and engineering on reactor portion now underway. Major construction at site to start in Spring 1959.

Experimental Breeder Reactor 2 (AEC–Argonne). Design and construction being carried out concurrently. Design of facilities to be completed early next year; construction began late last year and is to be completed by April 1960. Reactor containment capsule now undergoing acceptance tests.

Northern States Power Co. (Allis-Chalmers). Study of an integral nuclear superheater (NU, April '58, 22) has been completed and shows it is feasible and practical. Construction is to start in mid-1959.

Humboldt Bay (Pacific Gas & Electric–GE). Preliminary design for the nuclear unit is now well along. Construction is to start in Spring 1960 for mid-1962 completion.

Fermi Reactor (Power Reactor Development Corp.). Reactor vessel is now in position in containment capsule; thermal shielding is being installed. Turbine-generator, steam generator, control and office buildings are now under construction. Criticality is scheduled for September 1960.

Elk River (Rural Cooperative Power Assn.–ACF). Construction began Aug. 5, and reactor and superheater buildings are under construction. Temporary foundation for the former is complete.

Yankee (Yankee Atomic Electric–Westinghouse). Site preparation began in November 1957, and heavy construction began this Spring. The turbine building is virtually complete; the reactor sphere is to be finished in mid-1959. Equipment is to be installed during 1959; testing is scheduled for early 1960, and criticality for late 1960.

Reactor News

NDA, SARGENT & LUNDY GET D_2O STUDY

The team of Sargent & Lundy with Nuclear Development Corp. of America has been chosen by AEC from among 15 bidders to carry out a design study of a heavy-water-moderated power plant. AEC said a comparative evaluation of the technical feasibility and economics of various D_2O-moderated reactor concepts, using either natural or slightly-enriched uranium, will be made; based on this evaluation, plant concept and size will be determined and a preliminary design and cost estimate prepared for a prototype. However there is no commitment by AEC to build such a prototype. The study follows an earlier one made for AEC by duPont (NU, Dec. '56, R5), and parallels work on a Heavy Water Components Test Reactor duPont is starting to build for AEC at the Savannah River plant.

CHUGACH SEES 200-MW SDR IN ITS FUTURE

Site investigations for the $20-million Chugach Electric Assn. sodium-deuterium reactor have been completed, NDA and Burns & Roe engineer told an Anchorage group. They expect construction to start in 1961, and Chugach hopes to obtain from the 10-Mw(e) plant data for designing a 200-Mw(e) scale-up, which it wants to start building in 1965.

IDAHO TEST SITE EXPANDS

AEC's National Reactor Testing Station is planning to add another 140,500 acres to its existing 431,300; the new land, on the north and west, will provide additional exclusion area around the Aircraft Nuclear Propulsion site and will bring NRTS to 894 square miles total (the State of Rhode Island is 1,058 mi² in area). From NRTS also comes word that HTRE-2 and HTRE-3 have followed the first Heat Transfer Reactor Experiment (NU, Sept. '58, 74), and, together with a Hot Critical Experiment (called HOTCE) also for the ANP program, have already been in operation. Another revelation is that two AlW large ship prototype reactors (NU, Nov. '58, 28) can develop 70,000 shaft horsepower—~50 Mw(th).

AF CONTINUES ANP WORK AT GE, CONVAIR

General Electric and Convair Division of General Dynamics have been given contracts to continue their development work under the Aircraft Nuclear Propulsion Program; both have held AF contracts since 1951. A new contract for $39,369,000 went to GE and one for $2,671,557 went to Convair. Under the program, the AF has responsibility for developing turbomachinery and other nonnuclear equipment; AEC has reactor responsibility.

LICENSES: BR-2, FOUR RESEARCH UNITS

The first license for export of a U. S. power reactor was issued by AEC to Westinghouse last month, covering shipment of the 11.5-Mw(e) pressurized water reactor BR-2 for Mol, Belgium. The containment vessel is nearly completed at Mol, and the reactor vessel is to be shipped shortly; total value of U. S.-supplied components is placed at $4-million . . . AEC also proposed to issue construction permits for one industrial and three university reactors: the Cornell Dual-Core Reactor (NU, March '58, 25); a General Atomic Triga for the Univ. of Arizona; a 10-kw(th) pool for North Carolina State College, its second reactor (NU, June '57, 28), to be built by Nucledyne division of Cook Electric Co.; and a water-tank type critical experiment facility for Allis-Chalmers at Greendale just south of Milwaukee.

AI MEETING PIQUA SAFETY CRITICISM

Atomics International has moved to meet criticism of the safety of its Piqua, Ohio, organic-moderated power reactor project expressed in a tentative finding by the Advisory Committee on Reactor Safeguards in September (NU, Oct. '58, 27). It will add a 3/16-in. steel liner on the inner surface of the underground concrete caisson that will house the reactor, to reduce diffusion through the concrete (it is not a pressure shield; OMRs operate at low pressure). Also ventilation of the plant will be improved, with an iodine monitor that can cut in an iodine trap instantly. Finally, the site itself will be removed across the Miami river from Piqua city, and steam will be piped across the stream to the turbine-house. ACRS, according to government sources, has submitted a preliminary hazards report to AEC—but has asked for more information—to be considered by ACRS at a meeting this month.

TWO CONSTRUCTION BIDS ON PRTR

AEC's Plutonium Recycle Test Reactor (formerly PuRR), now under construction at Hanford, advanced with two new construction contracts. George A. Grant, Inc., of Pasco, Wash., was apparent low bidder at $218,800, among 12 bidders, on Phase 2A construction: concrete river pump, intake and condenser structures. Contract went to Shaw & Estes, Inc., of Dallas, low among six bidders on Phase 3 construction; its $1,587,000 bid was almost half AEC's $2,873,000 fair cost estimate. Work includes construction of the reactor vessel, thermal and biological shielding, process solution storage tank, primary and secondary coolant and moderator and reflector cooling systems, fuel handling and control equipment and other supporting systems.

TWO NEW METALLURGICAL LABS

A $4-million metallurgical research center combining laboratories with an integrated pilot production plant, will be completed by Olin Mathieson Chemical Corp. at New Haven, Conn., by mid-1959. Olin recently completed plant for assembly of reactor cores at Montville, Conn. (NU, Feb. '58, 26; Oct., 31) . . . At October's end, Nuclear Metals dedicated a $2-million metallurgical lab (*see p. 87*).

NORTHERN STATES TO SET UP CHECK POINTS

Northern States Power Co. has decided to establish now—at the site of its 60 Mw(e) reactor and five points in South Dakota, Minnesota and Iowa—monitoring stations for radioactivity. Over the 2½ years before operation of the plant, the company said, the stations will establish normal radiation levels to show after the reactor comes on stream that "there is no great hazard in using atomic fuel to power a generating station."

NEWS OF COMPONENTS

Westinghouse has ordered twelve half-ton or heavier radiation shielding windows that will permit A-sub crews to look directly into reactor compartments while at sea, instead of through a system of periscopes. The windows contain Plexiglas to shield against neutrons and high-density, lead glass against gammas . . . Sylcor has completed more than 5,000 new-design "cookie-cutter" fuel elements for the Brookhaven research reactor (NU, Feb. '57, R10) . . . A single trailer-truck delivered the first shipment of fuel elements, $1.7-million worth, from San Jose, Calif., to the Dresden reactor site. The 54 fuel bundles are the first of 488 for the first core loading.

ROUNDUP

World News

Britain Awards AGR Contracts

The U. K. Atomic Energy Authority has distributed a string of contracts for its Advanced Gas-cooled Reactor, whose foundations have been started at Windscale, adjacent to the two Pu-piles now shut down forever. Whessoe Ltd. will build the reactor vessel, English Electric the turbo-alternator, Associated Equipment and International Combustion Ltd. the heat exchangers, Babcock & Wilcox Ltd. the containment building, Hick Hargreaves Ltd. the dump condenser, Mather Platt Ltd. the feed pumps. Whatlings Ltd. of Glasgow will do the civil engineering, and Ewbank & Partners Ltd. were retained as consultants on the turbine end of the plant.

Bayernwerke Joins RWE at Kahl

Rheinisch-Westfälische Elektrizitätswerke AG of Essen, West Germany's biggest utility and builder of the country's first nuclear power plant at Kahl, and Bayernwerke AG of Munich, the big Bavarian utility, have set up a joint subsidiary, Versuchsatomkraftwerke Kahl GmbH (Kahl Experimental Atomic Power Plant Inc.). The new firm, with headquarters at Grosswelzheim near Kahl, will take over construction and operation of the 15-Mw(e) boiling water plant (NU, Nov. '58, 25); its manager is August Weckesser.

JAERI Retains Internuclear

The Japan Atomic Energy Research Institute has engaged Internuclear Co. "to provide consulting engineering services, . . . technical assistance in preparing specifications" in connection with JAERI's plan to buy a small U. S. pressurized or boiling water demonstration power reactor. Meanwhile press reports from London tell of "many difficulties causing delay" in the sale of a 150-Mw(e) British gas-cooled reactor to the Japan Atomic Power Co.

Chapel Cross Starts Up, Has Fire

The first reactor (of four) at Chapel Cross in southern Scotland went critical Nov. 9. As bad luck would have it, two nights later fire broke out in a turbine; however it was described as being minor. The Chapel Cross station is a duplicate of Calder Hall, with four identical reactors the last of which is to be completed in late 1959.

Switzerland Boosts Atomic Budget

The Swiss Federal Council has drafted an expanded program for nuclear research and development, and assigned a budget of $16-million for 1959–62. This compares with $11.8-million spent by the government in 1946–58. Of the $16-million, $9-million will be spent by the Swiss National Fund for Development of Scientific Research on additional research projects and for training specialists as well as for the normal graduate programs in atomic energy and radiation protection. $7-million will be earmarked for the applied research program of the Reaktor AG firm at its Würenlingen labs (NU, Aug. '58, 26). Eventually another $3-million is contemplated for the Zurich Polytechnic Institute's atomic program. If the program is ratified by Parliament, governmental expenditures for atomic energy will equal the total credits for all other scientific, research, cultural and art programs.

Brazil Buys a Triga

General Atomic has sold a Triga reactor, its sixth sale, to Brazil for the Univ. of Minas Gerais at Belo Horizonte. The 30-kw unit will be installed below ground. Earlier sales were to Austria, Italy, Belgian Congo, Vietnam, and the Univ. of Arizona.

Westinghouse in Framatome Firm in France

Westinghouse and seven French manufacturers have set up a new joint subsidiary, Framatome, to undertake complete reactor installations in the Euratom market, using Westinghouse techniques under license. Leading the French group of firms is the huge steel firm, Forges et Ateliers du Creusot, which has played a major part in the French reactor program.

One Yugoslav Victim Dies

One of seven Yugoslav atomic scientists flown to the Curie Hospital in Paris for treatment following an excursion in Yugoslavia's bare critical assembly has died of cardio-pulmonary complications and hemorrhage; the body, flown back from Paris, set off a wave of hysteria in France. All but one or two of the surviving six, one of them a woman, are in serious condition. Details of the accident are not yet available.

Design for Puerto Rican Power Unit OK'd

AEC has authorized negotiation of a contract covering design of a boiling water power reactor for Puerto Rico (NU, May '57, 23; Aug. '57, 19). General Nuclear Engineering Corp. will do the design study for the Puerto Rico Water Resources Authority. The reactor would incorporate a nuclear-fired superheater. Cost to AEC for the design study is placed at $250,000.

Czechs Design Automatic Control System

The Reactor Laboratory Institute of the Czechoslovak Academy of Sciences says it has designed a system permitting fully automatic measurement and control of reactors. Instead of using a family of neutron flux detectors in fixed positions throughout the core, the system would use a single chamber at constant sensitivity by moving it further away from the core as the flux level increases. The moving chamber is physically linked to the control rods, thus, it's claimed, reducing the number and intricacy of present control gear.

Atomists on the Move

Chairman McCone and Commissioner Libby of AEC visited Britain last month to study the UK power program and to discuss with AEA officials the Anglo-American bilateral. They inspected Calder Hall, Windscale, Dounreay and Harwell . . . A two-man exploratory mission of the International Atomic Energy—B. V. Nevsky of the U.S.S.R. and Victor Thayer of the U. S.—has gone to Cairo to advise the United Arab Republic government on the technical and economic feasibility of producing uranium from Egypt's abundant phosphates and of making D_2O by the electrolytic method as a by-product of an ammonium nitrate fertilizer factory now being built at Aswan. . . . Peter C. Thonemann, head of British thermonuclear research, will take a year's leave to study at the Institute for Advanced Study at Princeton, N. J. Part of a general policy of freer interchange between U. S. and British scientists, the move will see a senior astrophysicist from Princeton going to Harwell for a year's study. During Thoneman's absence, research with Zeta and plans for Zeta-2 will continue under R. S. Pease.

News in Brief

ORNL Gets Go-Ahead on Lab Additions

Oak Ridge National Laboratory will add more than 350,000 sq ft of work space to its central research and instrument laboratories at a cost of $9.6-million. Decision to proceed with the expansion is something of a victory for the Joint Committee on Atomic Energy, which had insisted that AEC be given the construction funds this year (over Budget Bureau objections). The additions will bring together more than 500 ORNL employees working in scattered locations. Bids for construction of two additions to the central lab (307,000 sq ft total) have already been received; bids for the instrument-lab addition (47,500 sq ft) will be opened about Jan. 15.

AEC to Seek Doubling of Isotope Funds

The Administration is expected to ask Congress to double in fiscal 1960 the current budget for AEC's Isotope Development Program; $4-million was appropriated for the current fiscal year ending June 30 (NU, Oct. '58, 21). Paul Aebersold, program director, told the annual meeting of the Atomic Industrial Forum that the program had been set up for five years from a budgetary standpoint, with an upper limit of $15-million for any given year. He said an estimated 75–100 applications for program contracts had been received through mid-November. A contract was recently awarded to the Textile Institute of North Carolina for the study of radiation applications in the textile industry; expiration date is June 30.

State Dept., McCone Under U-Industry Attack

The uranium industry is loudly criticizing the State Dept. and quietly criticizing AEC Chairman John A. McCone: the former for its insistence on fulfilling this country's uranium-purchase commitments abroad until they expire in the early 1960's, the latter for spending too much time away from his desk. Gordon A. Weller, executive vice president of the Uranium Institute of America, made it clear last month that the industry feels it is bucking State Dept. influence in UIA's efforts to destroy "the price advantage" of "$1.53 per pound" purportedly enjoyed by foreign suppliers of U to AEC. The State Dept., he charged, "stands ready to maintain and protect the agreements which were made abroad." McCone is being accused privately by industry officials of delaying AEC approval of U-milling expansion already cleared by the AEC staff—at alleged losses to the firms involved (NU, Nov. '58, 27). Industry officials accept the McCone visit to the Vatican as Presidential representative, but they are looking askance at the time he has given to entertaining the Queen of Greece and combination business-pleasure trips to Europe (*see page 26*).

ASA Forming Subcommittees on Radiation

The American Standards Association is recruiting members for two new radiation subcommittees of its committee on chemical engineering for the nuclear field. The first subgroup will develop standards for the use and handling of radioisotopes and high-energy radiation sources; the second will work on standards for packaging and transportation of radioactive material. Contact A. C. Jealous, Union Carbide Nuclear Co., 30 E. 42nd St., New York City; or Charles R. Russell, General Motors Corp., Warren, Mich.

AEC Kills Guaranteed Price for New U Sales

AEC advised uranium-concentrate suppliers last month that its guaranteed price of $8/lb will not be available beyond April 1, 1962, except for existing commitments and new commitments made under the limited expansion program announced last April (NU, May '58, 24). These commitments will be honored at the guaranteed price until Dec. 31, 1966. Effect of the action is to freeze the price-guarantee program at the current level of purchase commitments.

Nuclear Statistics—by AEC, Census Bureau

The Census Bureau, in cooperation with AEC, has mailed questionnaires to "atomic energy manufacturers and processors" in the first attempt to compile statistics on the industry's business—number and value of shipments, product manufacture, processing of raw materials and byproducts. Data collected this year will be published as a report of the 1958 Census of Manufactures, then annually thereafter.

Joint Committee Studying Patent Picture

David Toll, staff counsel for the Joint Committee on Atomic Energy, disclosed at a patent symposium of the Atomic Industrial Forum meeting last month that he is directing a comprehensive investigation of the patent provisions of the 1954 Atomic Energy Act and experience under it. The study also includes a look at the general patent system in the U. S. A staff report will go to JCAE members in January, he said, in anticipation of open hearings later in the year (the compulsory licensing provisions of the 1954 Act expire on Aug. 31, 1959). Earlier in the symposium, Roland T. Bryan, Babcock & Wilcox attorney, urged an end to compulsory licensing. He said no private reactor patents have ever been filed; then added that, with 8 reactor manufacturers and 14 fuel-element fabricators now in business, the original reason for compulsory licensing (anti-monopoly) no longer existed.

New Requirement on Materials Handling

Licensees of AEC handling sizable amounts of enriched-uranium and plutonium have been ordered by AEC to set up alarm systems and emergency plans for evacuation of personnel. Subject to the requirement are those possessing more than 500 gm contained U^{235}, 300 gm Pu, or 300 gm U^{233}. Most of the more than 200 licenses authorizing possession of special nuclear material use small quantities and will not be affected by the rule.

News in Brief Notes

AEC last month invited industry comments on a proposed change in its radioisotopes regulation, which would set safe limits for radioactive concentrations in consumer goods (except foods, drugs and cosmetics) and exempt from licensing users of such goods. AEC would pass on each item marketed by its licensees. Industry comments were due Nov. 30. . . . The AFL-CIO has created an atomic energy technical committee representing 14 affiliated unions; chairman is Benjamin C. Sigal, general counsel, International Union of Electrical Workers, and chief of staff for the several unions active in the Fermi-reactor case before AEC. . . . Atomics International will begin this month to occupy its new headquarters at 8900 De Soto Ave., Canoga Park, Calif. A 132,000-sq-ft building has been completed; others totalling 242,000 sq ft will be ready late next year. . . . New Yorkers are forming a chapter of the Health Physics Society.

Forum Speakers Report On Foreign, U. S. Liability

Robert Eichholz, director of an Atomic Industrial Forum – Harvard Law School study on the international aspects of nuclear hazards problems, gave a preview last month of his group's final report, due this month or early next. He spoke at the Forum's annual meeting in Washington, where the same audience also heard a report on the domestic liability situation by Robert Lowenstein of AEC's Division of Licensing and Regulation.

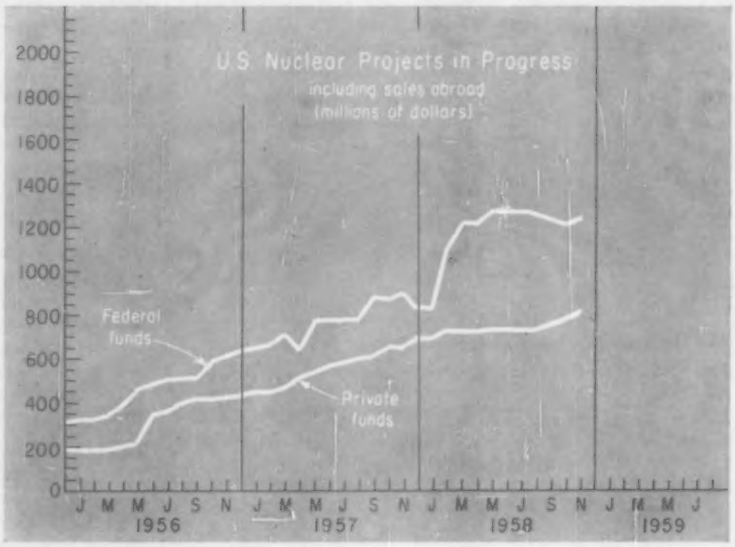
Eichholz' hint of the recommendations his group may make indicated that its work over the past year has closely paralleled that of a European insurance group, which recently prepared a draft liability treaty for the Organization for European Economic Cooperation (NU, Nov. '58, 23). At least seven of the 12 points urged by Eichholz for inclusion in any international or national liability law are covered by the OEEC treaty:

- Absolute liability of a nuclear plant operator.
- Limitation of the operator's liability.
- Operator must maintain protection up to his legal limitation.
- Jurisdiction over all damage claims by local courts.
- Local law should govern all liability questions.
- Limitation of the period for filing claims.
- Access to local courts, on an equal basis, for all injured parties, without regard to nationality, etc.

The following points, which are not in the proposed OEEC convention, were also recommended by Eichholz: licensing of all operators; freedom from liability for all suppliers (except by contract with the operator); coverage for transportation; ratable reduction of judgments where they exceed operator's financial protection; and a commitment by each country to extend protection beyond that required by the operators.

Lowenstein's summary of industry comments on the proposed liability agreements of AEC and two commercial insurance pools showed that industry feels the language of each contains serious deficiencies. The policies of the Nuclear Energy Liability Insurance Assn. and the Mutual Atomic Energy Liability Underwriters would cover facilities up to the point where AEC indemnity coverage would take effect.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for federal projects ($10³)	5,725	12,043	9,583
Proposed construction, privately-owned ($10³)	4,000	0	0
Contracts awarded, private work ($10³)	0	0	9,500
Backlog of private projects ($10⁶)	254	249	226
Access Permits †—			
Access permits issued	6	6	25
Total access permit holders	1,409	1,419	1,381
Isotope Use †—			
Applications for isotope use	652	540	344
Cumulative total of isotope users	4,323	4,236	4,353
ORNL shipments (curies)	14,300	20,642	20,856
Public and private export shipments	339	112	407
Employment †—			
AEC employment	6,911	6,972	6,852
Construction and design contractors' employment	11,659	10,780	11,581
Total operating contractors' employment	103,389	104,502	99,150
Production workers	51,153	51,119	50,577
Research and development employees	45,986	47,153	41,822
Miscellaneous workers	6,250	6,230	6,751

U. S.-built Reactors ‡—

	Operating	Building	Contracted
Power, domestic	1	7	7
Power, for export	0	1	3
Power experiments and pilot plants	7	4	1
Military and naval	6	23	22
Research and test, domestic	51	18	45
Research and test, for export	11	15	10
Foreign-built Reactors ‡—			
Power, domestic	8	23	7
Power, for export	0	1	1
Research and test, domestic	28	15	9
Research and test, for export	6	6	1

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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Pulse Height Analyzers. The most revolutionary instrument in the analyzer field today is the completely new, all transistorized RCLiac 128 Scaler-Analyzer. The RCLiac 128, shown second from the top, performs every operation from gross counting through scintillation-spectroscopy.

RCL's 256-Channel Pulse Height Analyzer, (top right), is *The Analyzer* of proven reliability — from 10 seconds to 27 hours of preset time, background subtraction, automatic programming, split memory, decimal and logarithmic readout, and many other new features. RCL also offers 1024-Channel Neutron Time-of-Flight Analyzers, Single Channel Differential Analyzers, and both Recording and Medical Spectrogammeometers.

Instruments. RCL instruments are of the finest design, construction and workmanship in the nuclear field. Among the many instruments manufactured by RCL are Linear Amplifiers, Scalers, Linear and Logarithmic Count Rate Meters, Precision High Voltage Power Supplies, and Precision Pulse Generators. All instruments suitable for standard 19" rack mounting. Cabinet supplied, if desired.

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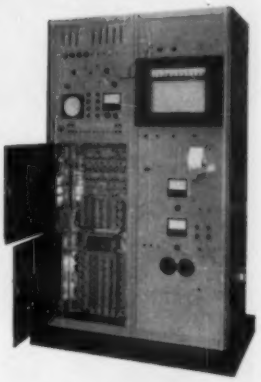
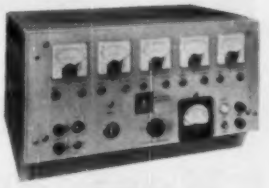
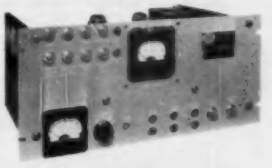
Reactor Controls. The first nuclear reactor controls manufactured by a non-AEC facility were supplied by RCL. Today, RCL reactor control instrumentation — such as Log N, Period, Sigma, Magnetic and Composite Safety Amplifiers, Log Count Rate Meters, and Power Supplies — can be found in reactor installations throughout the world.

Detectors. Among the many different types of detectors produced by RCL are Alpha-Beta, Gas Flow, Beta-Gamma Thin Wall, Gamma, Fast or Slow Neutron, Gas Sample, Cosmic Ray, Scintillation, Halogen Quenched Beta-Gamma, and Ionization Chambers.

Accessories. RCL can fill almost every accessory need immediately. For your convenience RCL keeps a constant supply of items such as radiation shields, sample holders, sources, safety equipment and clothing, timers, glassware, scintillation crystals, sample preparation and handling equipment, etc.







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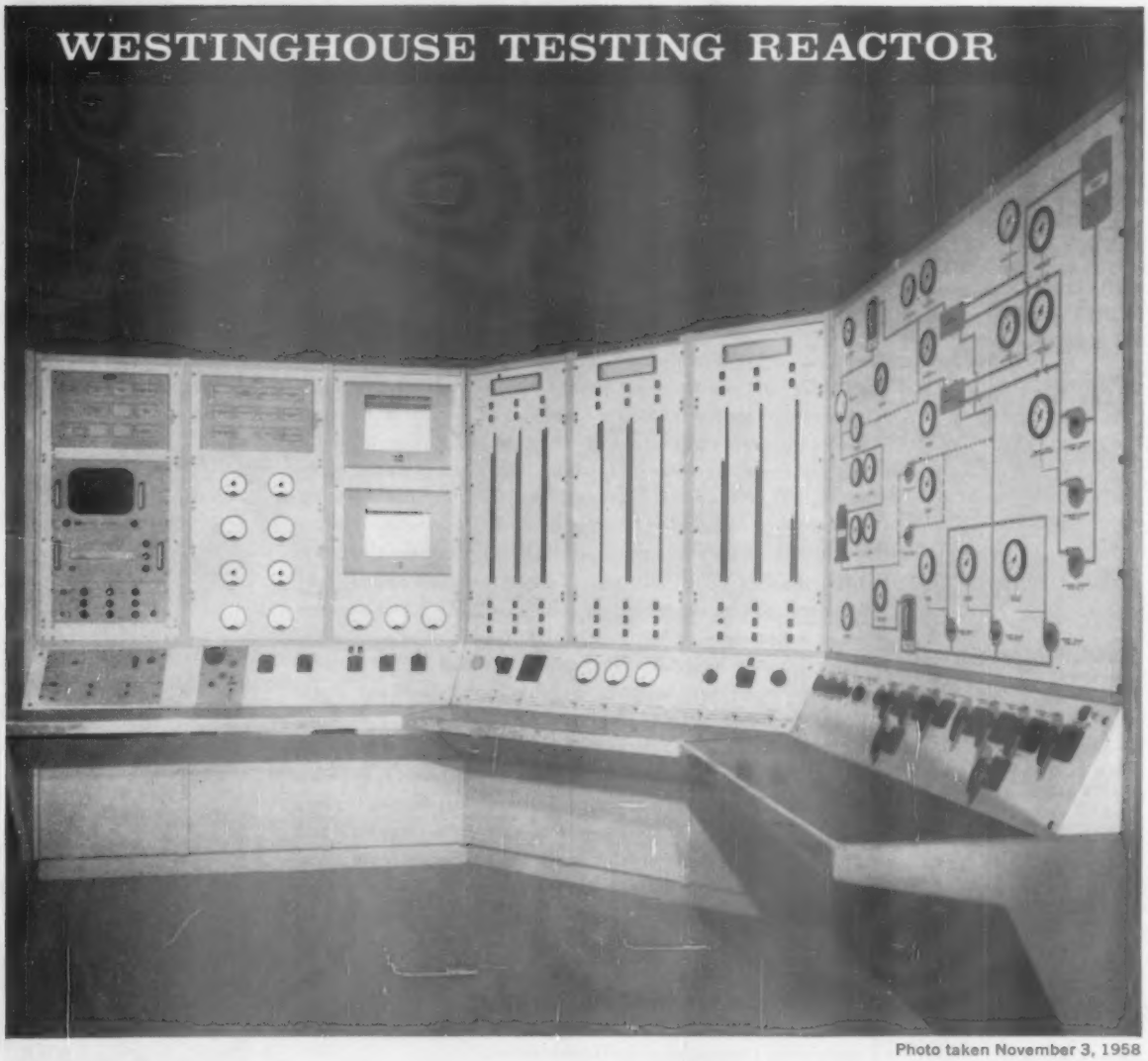

Photo taken November 3, 1958

Equipment Installations Keep Pace with Over-all Construction

The control console, nerve center for all reactor operations, has been installed in the reactor control room at WTR. With much other equipment already in position, circuit wiring is being completed rapidly, and on schedule.

By early spring, 1959, this 20-mw reactor will be available to industry for high-flux irradiation experiments, including those conducted under high-temperature and high-pressure conditions. Auxiliary services will include: hot cells, reactivity measuring, critical experiment and gamma irradiation facilities.

For contract reservations and assistance in planning tests of your nuclear materials, write: Westinghouse Testing Reactor, P. O. Box 1075, Pittsburgh 30, Pennsylvania. J-59006

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Casting specifications and inspection requirements for nuclear application are thoroughly understood at *ESCO*. Equipped with the finest facilities and the technical know-how, *ESCO* welcomes the toughest casting assignments. Ask your nearest *ESCO* representative for details or write direct.

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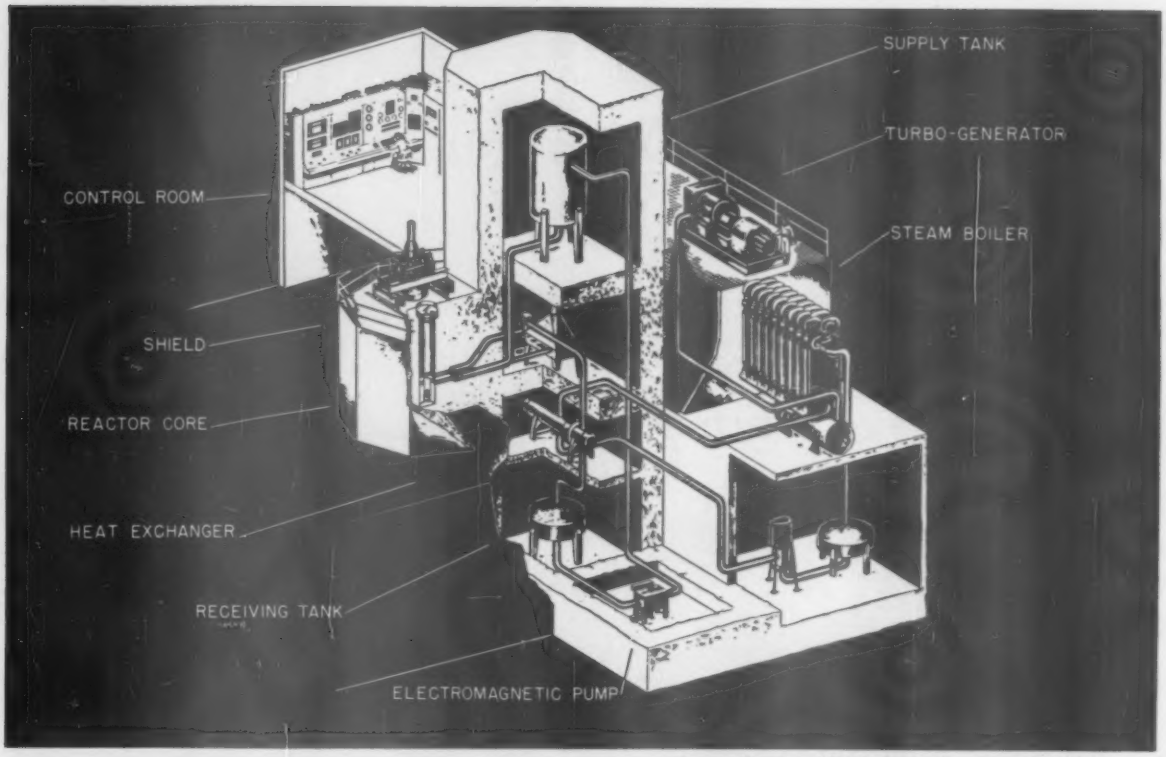

Drawing of EBR-1 courtesy Argonne National Laboratory

7 YEARS OF SATISFACTION WITH SODIUM COOLING:

That's what they said about EBR-1 at Geneva. No variation has been detected in performance of valves, pumps and steam generator since start-up in December, 1951.

Almost everyone concerned with atomic energy immediately spots the illustration above as a simplified drawing of the Experimental Breeder Reactor and Steam-Electric Generator (EBR-1) at Arco, Idaho. It is well known, too, that its coolant is NaK—an alloy of sodium and potassium.

This reactor was built to demonstrate breeding and to produce electricity, and has been successful on both scores. EBR-1 generated the world's first electricity from atomic energy on December 22, 1951. Subsequently, its breeding rate was measured at 1.04.

EBR-1 has also proved the dependability of the liquid metal heat exchange system it employs. This fall, at the 2nd International Conference on Peaceful Uses of Atomic Energy at Geneva, Argonne National Laboratory's Dr. F. A. Smith reported that all components have operated reliably since initial start-up. There has been no indication of any drift in sodium pressure, flow or level; no variation in valves, pump and steam generator over the plant's seven-year life.

These are the properties of sodium which the ANL scientist says make it the best heat transfer medium for a fast breeder reactor:

- High thermal conductivity
- High heat transfer rates at moderate velocity
- Low film coefficient for heat transfer
- High boiling point
- Reasonably low melting point
- Low cost

For further information on sodium, write for our brochure, "Handling Metallic Sodium on a Plant Scale". If you have specific problems, our technical service department will be glad to help you.

FIVE OTHER SODIUM-COOLED REACTORS

- PRDC Fast Power Reactor, Monroe, Mich.—fast breeder—100,000 KW (under construction)
- Consumers Public Power District, Hallam, Neb.—graphite moderated—75,000 KW (design stage)
- Experimental Breeder Reactor-2 (EBR-2) NRTS, Arco, Idaho—fast breeder—20,000 KW (design stage)
- Chugach Electric Association, Anchorage, Alaska—heavy water moderated—10,000 KW (development stage)
- Sodium Reactor Experiment (SRE), Santa Susana, Calif.—graphite moderated—6,500 KW (operational)

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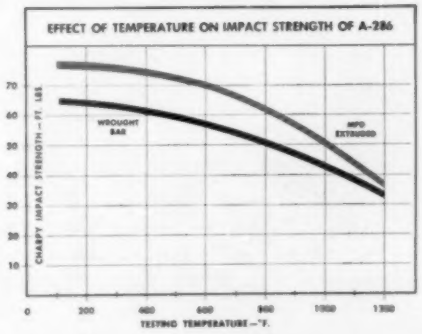
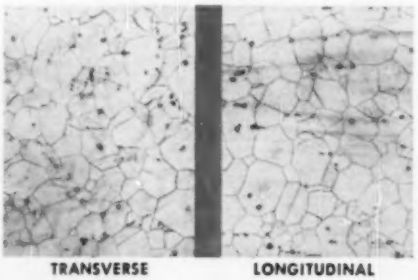


CURMET quality is more than inspection . . . though the most modern flaw detection methods are employed . . . it is the *in-process control of metal flow* that imparts premium properties and adds to service life.



TRANSVERSE LONGITUDINAL

CURMET processing with accurate metallurgical control is typified by this microphoto of a precipitation hardening, high temperature alloy extrusion (A-286) showing uniform longitudinal and transverse grains. Metallurgical examination of the extrusion shows uniformity of microstructure, assuring consistently high mechanical properties throughout the full length.

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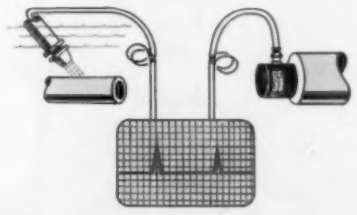

IMMERSION TESTING — OR — CONTACT TESTING

Permissible ultrasonic flaw indication for commercial products is 5% of wall thickness. Nuclear applications are specified at 3%. High-performance A-286 alloy, when CURMET processed, consistently passes ultrasonic testing at the 1½% level . . . with no defects noted even under these rigid test conditions.

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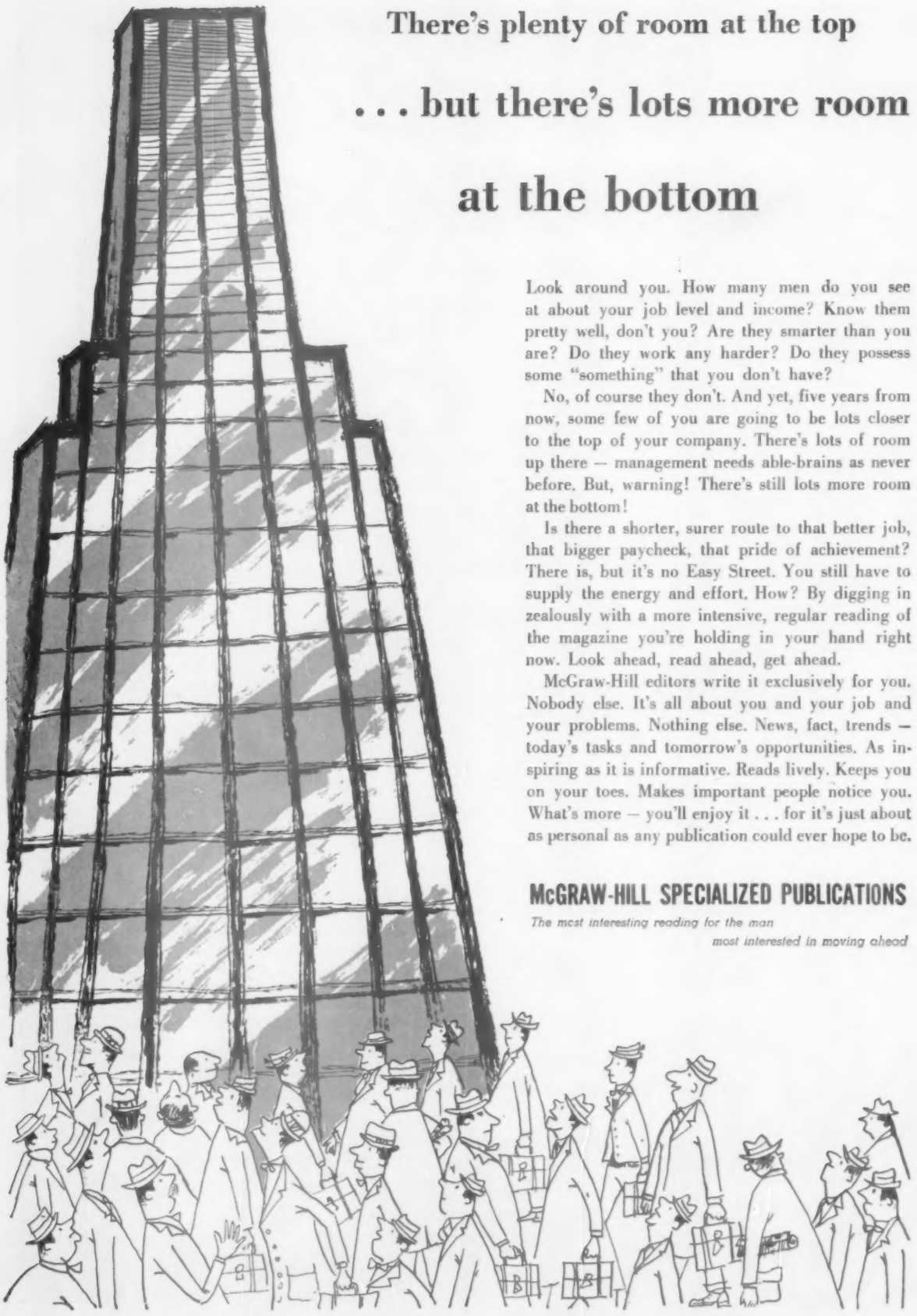
There's plenty of room at the top

. . . but there's lots more room at the bottom



Look around you. How many men do you see at about your job level and income? Know them pretty well, don't you? Are they smarter than you are? Do they work any harder? Do they possess some "something" that you don't have?

No, of course they don't. And yet, five years from now, some few of you are going to be lots closer to the top of your company. There's lots of room up there — management needs able-brains as never before. But, warning! There's still lots more room at the bottom!

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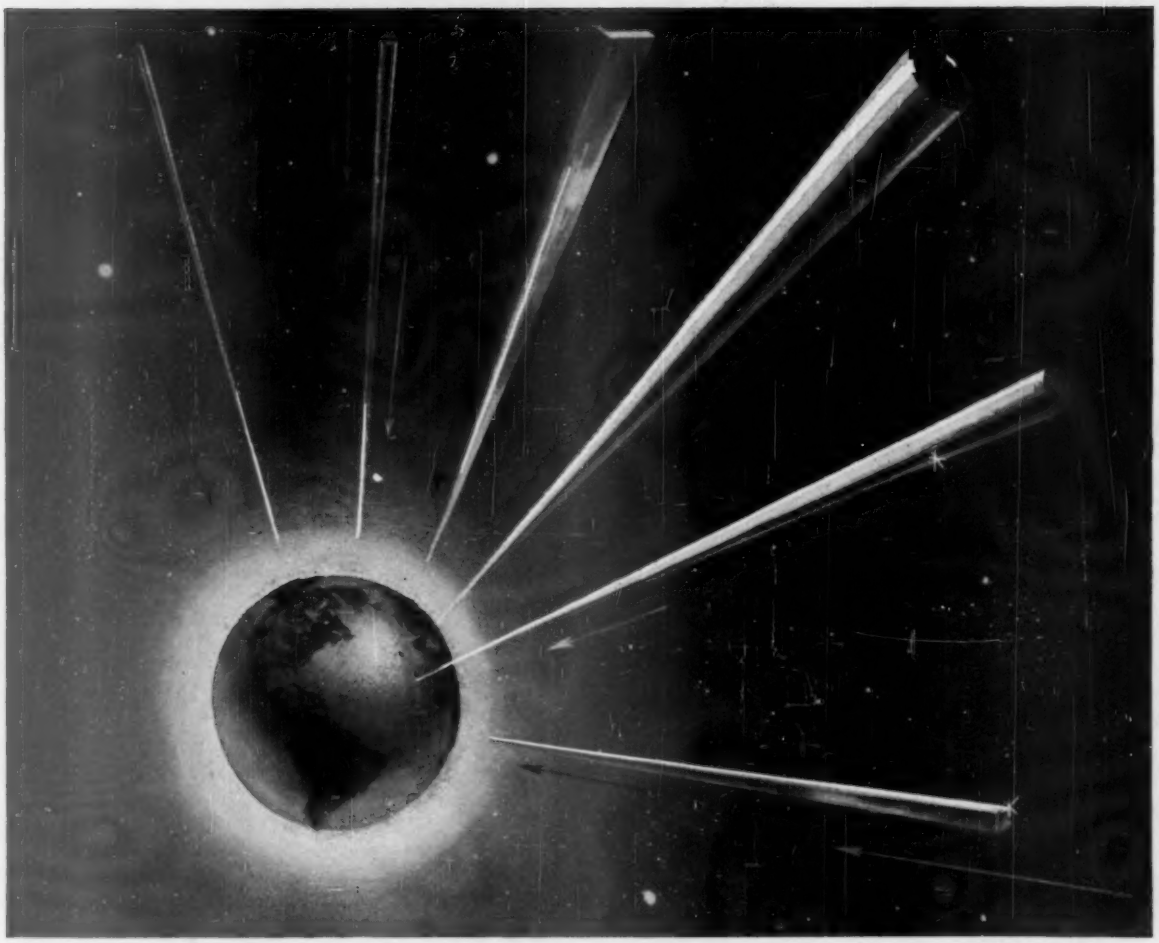

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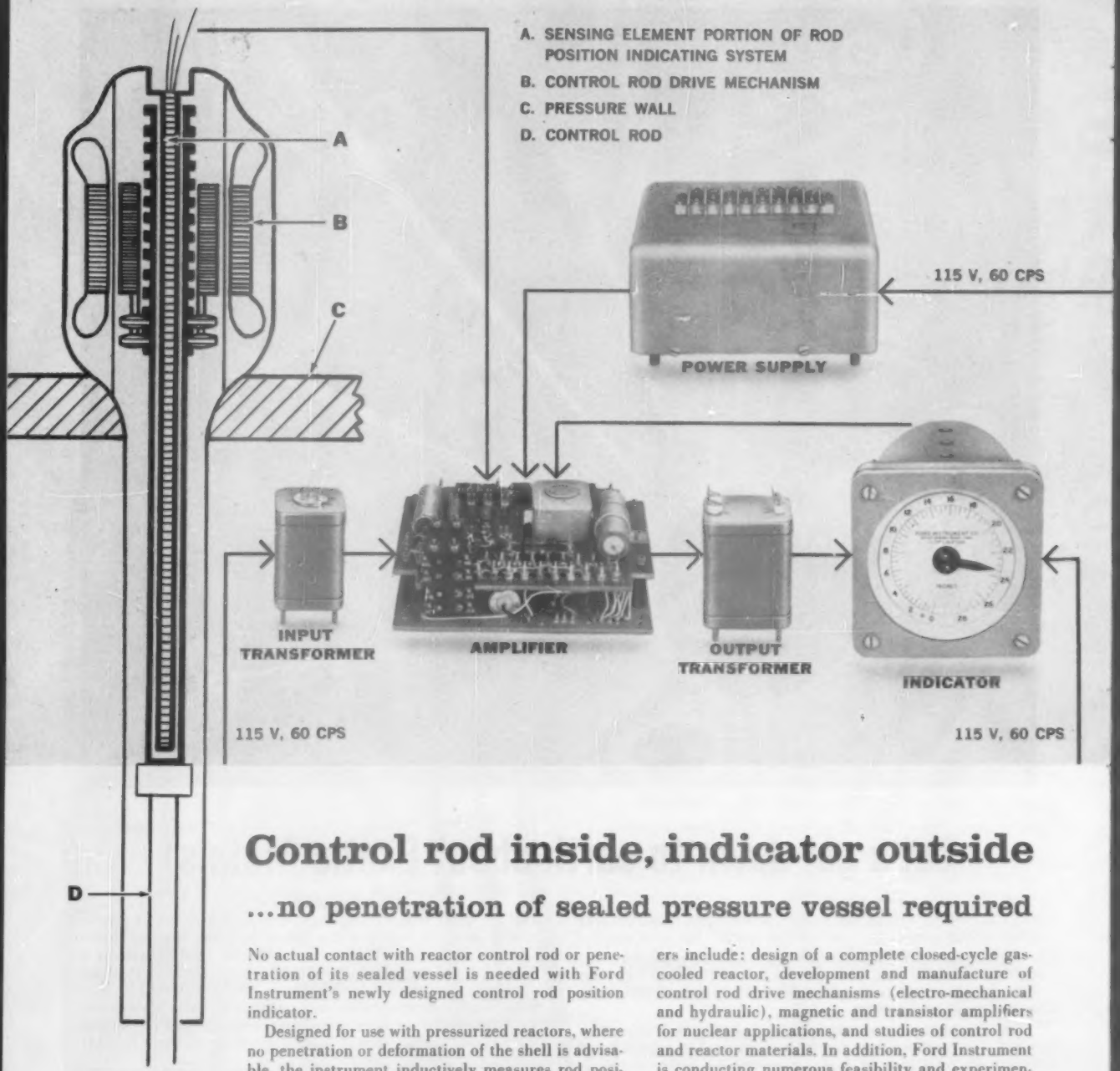

Control rod inside, indicator outside

...no penetration of sealed pressure vessel required

No actual contact with reactor control rod or penetration of its sealed vessel is needed with Ford Instrument's newly designed control rod position indicator.

Designed for use with pressurized reactors, where no penetration or deformation of the shell is advisable, the instrument inductively measures rod position, from outside the vessel, and electrically transmits the position information to a remote dial indicator located almost any distance away. Completely transistorized, using printed circuit techniques, the system is compact and suitable for mounting within standard instrument cabinet drawers.

This control rod position indicator system is only one of the advanced nuclear developments completed, or in progress, at Ford Instrument Co. Others include: design of a complete closed-cycle gas-cooled reactor, development and manufacture of control rod drive mechanisms (electro-mechanical and hydraulic), magnetic and transistor amplifiers for nuclear applications, and studies of control rod and reactor materials. In addition, Ford Instrument is conducting numerous feasibility and experimental studies in the nuclear field, including the application of digital techniques to reactor control and the operation of control components at high temperatures.

Our nuclear engineers will be glad to give you further information on the Ford Instrument control rod position indicator, or to discuss solution of your specific nuclear problems in the other areas mentioned above. Write: Nuclear Sales, Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.

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APPLIED RADIATION
DECEMBER, 1958

A Test Case

THE story on p. 24 of this issue reports on the considerable progress being made on 17 reactor projects in the U. S. The sum total of the experience represented by this rather diverse program is what is keeping the U. S. in the forefront of reactor technology.

But as exciting as this progress is, there is now almost universal recognition within the U. S. that reactor building must be stepped up if we are to achieve economically competitive nuclear power somewhere in the U. S. in the next decade, a goal that has been laid down by both Congress and the Administration.

The questions that still remain unanswered are: what kinds of reactors should be built, by whom, and under what arrangements? The Joint Committee on Atomic Energy has been canvassing national opinion on this.

One basic point of contention that apparently still very much exists is who shall pay for and own so-called "first generation" power reactors to be built in the years immediately ahead. (There does seem to be agreement that industry will own "second generation" plants, even if built with some AEC assistance.)

We made a statement on this earlier this year to the Joint Committee that read, in part:

"The ambitious program that needs to be initiated calls for the closest coordination between Government and industry. We need to have a strong governmental setup for the advanced thinking necessary, as the underpinning for our atomic economy. We need to have a strong nuclear industry for the carrying out of applied technology. Both have a vital role to play.

"It should be expected that over the life of, say, a 10-year program, some ideas will evolve that will look more interesting than they did at the outset. Other ideas, including certain reactor types, may look less interesting as time passes. This suggests the need for flexibility in the whole approach.

"There should be no fear of abandoning ideas or projects if they prove to be uninteresting from the economic or technical point of view. We should not wed ourselves to any particular reactor or approach just for the sake of having one of that particular kind. We should be looking for sophisticated and useful results.

"The overriding influences on whatever course of action is followed are:

1. A specific objective must be achieved, including, in part, the building of certain kinds of reactors; and
2. A strong and efficient nuclear industry must be fostered.

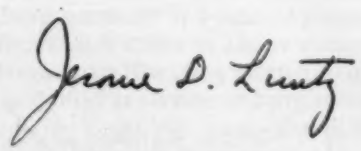
"The first objective is not in any way incompatible with giving industry a major role in the building of reactors called for under a new program. Industry can make major contributions to achieving the desired time schedule and to reducing nuclear power costs.

"The Government should not foot the entire bill. Rather, industry should be given incentive to spend its own money backed up by some form of subsidy that would be justified by the international considerations involved. . . . Industry would only take on projects where it felt it would be agreeable to taking risks beyond commitments made by the Government. Where no industry takers were available, and this would have to be determined in a reasonable, short period, the Government would handle the job in question.

"Because the goals of the program should be tied directly to the national security of the United States, in that the program would be an implementation of foreign policy, industry, as a partner of the Government, would feel just as motivated and obligated as the Government to stay the route in any project it undertook. Of course, as pointed out before, there should be some basis for agreeing on stopping projects where experience warrants it."

THERE is now a test case of this philosophy before the AEC, and soon before the Joint Committee. This is the gas-cooled project proposal (p. 17). Earlier this year Senator Clinton Anderson suggested that AEC build this plant and not seek proposals from industry. And there is still some Joint Committee sentiment that AEC should build this plant, even considering this new proposal.

It would seem prudent and economical for the government to encourage this kind of boldness and risktaking on the part of industry. By so doing, the advent of competitive nuclear power will certainly be hastened.



N.S. Savannah Progress Report:

Checking the concentricity of the outside and inside diameters and the machined surface on top of giant forging for N.S. Savannah reactor vessel.

B&W Completes 22-Ton Bolting Flange For World's First Nuclear Powered Merchant Ship

This huge bolting flange is part of the vital seal for the reactor vessel of the world's first nuclear powered merchant ship—the N.S. Savannah. Recently completed at B&W's Barberton Shops, the flange is a forged ring weighing approximately 44,500 pounds—over 10 ft in diameter and 2½ ft thick. Specifications called for stainless steel cladding and, despite its great size and weight, *precision tolerances of .005 in. linear and 0° - 30′ angular.* It contains tapped holes into which closure head studs are installed for retention of a formed hemispherical 9-ft diameter head. The completed reactor vessel, of which this precision-built flange is an important part, will stand nearly 27 ft high, and is designed to operate at 2000 psig at a temperature of 650 F.

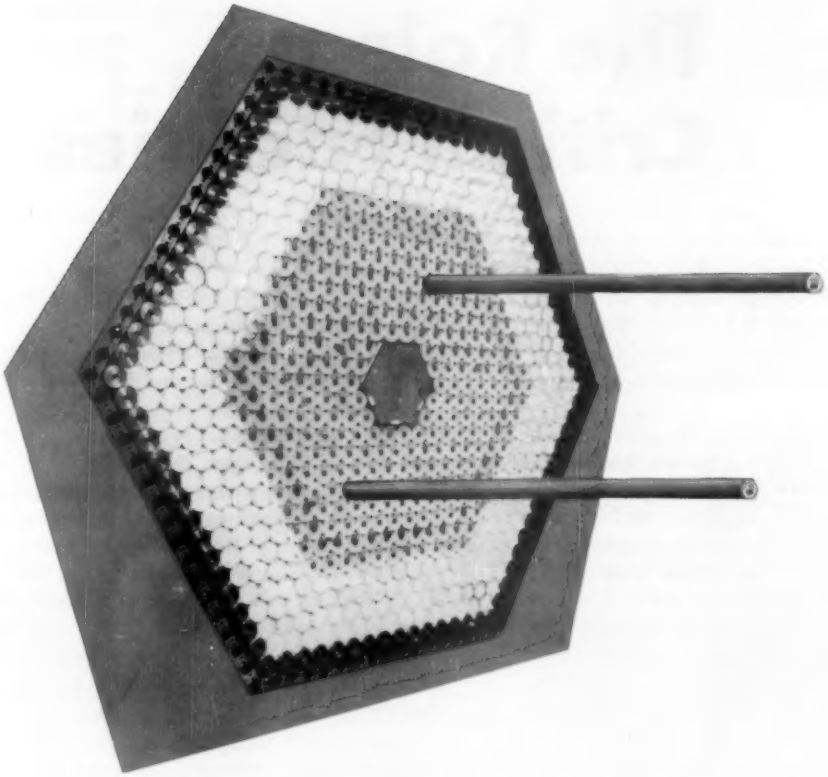
The experience, skills and facilities developed to produce heavy equipment for the steam generating, petroleum, pulp and paper and process industries have earned B&W a position of leadership as manufacturers of heavy nuclear components. The precise tolerances required present new and unusual manufacturing problems—but problems which are being successfully solved by B&W's skilled engineers and craftsmen.

For nuclear components—or complete nuclear power systems—consult The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, N. Y.

BABCOCK & WILCOX

BOILER DIVISION

NC-101



Critical Facilities in Nuclear Technology

Since the Preliminary Pile Assembly (above) began operation at Knolls Atomic Power Laboratory in 1948, it has gone critical over 12,000 times. This remarkable record of service points up the essential responsibility shared by the fifty or so critical facilities now operating in the U. S. for supplying the nuclear community with both design information and fundamental data.

In this issue, NUCLEONICS looks at the use of **Critical Facilities for Reactor Design (p. 40)** and for **Basic Physics (p. 42)** and speculates about **Critical Facilities Tomorrow (p. 43)**. A NUCLEONICS **Survey (p. 44)** summarizes information about the critical facilities now operating in the U. S. A new kind of research tool—the **High-Temperature, High-Pressure Critical Facility**—is introduced on p. 46. Battelle offers advice on **Building and Operating a Critical Facility (p. 48)**, while the **APPR Zero-Power Experiments (p. 51)** present a sample experimental program.

A NUCLEONICS REPORT ▶

The Role of Critical Facilities

Today's nuclear technology depends on critical facilities for information in four important areas: 1) reactor design, 2) weapons-systems design, 3) criticality limits on processing operations and 4) basic physics data.

By far the largest number of the critical facilities in the U. S. are devoted to reactor design. In these the experimenter seeks to achieve a delicate balance between neutron production and loss over the full range of reactor operating conditions.

For processing-operation critical experiments, the emphasis is on setting safety limits to ensure that batches of fissionable materials will never support a self-sustaining reaction in operations such as storage and shipping, isotope separation, chemical processing of irradiated fuel and fertile material, and fabrication of fuel elements. Through critical experiments, safety factors are established for systems of varying geometry, composition, fuel concentration and degree of coupling.

In contrast, weapons criticals are concerned with the understanding of supercritical assemblies with very short neutron lifetimes. Hence such experiments concentrate on determining the static and kinetic behavior of unmoderated nuclear systems.

Critical facilities that perform any of these first three functions can also be used to obtain basic physics information. In addition much useful data has come from "pure-geometry" critical assemblies constructed especially for physics experiments.

1. Critical Facilities for Reactor Design

By W. C. REDMAN, *Argonne National Laboratory, Lemont, Illinois*

IN MANY WAYS the critical facility bears the same relation to reactor design as the wind tunnel does to aircraft design. Just as the aeronautical engineer at a certain point in the design process looks to the wind tunnel for crucial information so the nuclear engineer must check out his proposed reactor design in a critical facility before he can confidently begin construction of the full-scale reactor.

In principle, a complete knowledge of all of the pertinent neutron cross sections and yields as a function of energy would enable the reactor designer to calculate the neutron distribution in space and energy and thereby specify the reactor configuration in all detail. In practice, the large gaps in our knowledge of the nuclear interaction parameters and the limited accuracy of many of the existing data make the use of refined theories and improved calculational techniques of questionable value in reactor design.

For example, theoretical calculations predicted a reference design loading for EBWR of 42 fuel assemblies with a probable error of $\pm 3\%$ in k. As such calculations go this one would appear reasonably accurate; however, in terms of fuel loading $+3\%$ corresponds to almost a factor of two in fuel load—some 40 extra fuel assemblies. For EBWR the observed loading fell just within the probable error, requiring a total of 81 assemblies. A much more accurate estimate for the loading could have been given by a critical experiment—and in fact this is what the first EBWR runs were used to do (NU, July '57, 60).

A critical experiment can be compared to a computer in which a Monte Carlo type of calculation is performed. The appropriate neutron cross sections are inherent in the system being studied, and the life histories of a tremendous quantity of neutrons are "calculated" simultaneously. Thus critical experiments afford a means of obtaining required answers without a knowledge of the neutron cross sections. Analysis of the results of critical experiments enables the reactor theorist to arrive at better parameter values for use in reactor-design calculations.

Experimental Objectives

Critical experiments serve primarily to yield information on the nuclear performance of the heart of the reactor system—namely, the reactor core and reflector.

Working within the limits set by heat-transfer, metallurgical and nuclear considerations, the critical experimenter seeks an optimum design. Variables typically at his disposal include quantity and enrichment of fuel, amount of moderator, dimensions of the reactor, lattice spacing of fuel channels, arrangement of fuel in the channel, area of coolant channel around fuel, physical properties and pressure of

coolant and parasitic absorber present as cladding and structure.

Changes in design that improve heat transfer, such as decrease in coolant-channel flow length, increase in size of channel, flux flattening, decrease in moderator-fuel ratio and subdivision of the fuel for increased heat-transfer surface, usually affect the neutron economy adversely. Consequently, a combination of heat-transfer and critical experiments is desirable to achieve a reliable core design.

Typical Program

The duration of the critical experiments depends upon several factors including the novelty of the reactor design, the importance of reliability in operation, the amount of pertinent data otherwise accumulated prior to startup and pressure to achieve early operation of the reactor.

Exponential experiments. If time permits and if materials that make possible a reasonable simulation of the proposed design are available, a series of exponential experiments may first be initiated to explore nuclear characteristics of assemblies having a range of values for lattice spacing, clustering, fuel concentration, enrichment, etc. Exponential experiments involve a thermal-neutron source plus an assembly containing only a fraction of the material required for a critical assembly with its self-sustaining chain reaction. Generally, an exponential program includes only a measurement of buckling of a particular system although the availability of a high-intensity neutron source, such as a thermal column of a power reactor, makes possible the measurement of lattice parameters and neutron spectra. The main advantage of an exponential assembly is that the system is operated well below criticality and consequently requires no elaborate instrumentation, control and shielding systems. The disadvantage is that the accuracy of information observed is limited and results of measurements of nonuniform systems require extensive analysis and involve uncertainties in interpretation.

Critical experiments. Once a tentative configuration and size for the core have been chosen either by calculation or by exponential experiments, detailed knowledge of the nuclear characteristics of the proposed design is determined through a series of critical experiments.

The initial phase of a typical program will include:

- determining the cold, clean critical mass by step-wise addition of the selected materials
- determining reflector savings from measurements of radial and axial flux distributions
- evaluating the factors comprising k_∞ from observed fission, capture and flux patterns in a representative lattice cell
- measuring the migration area ($M^2 = \tau + L^2$) by adding distributed nuclear poisons or making dimensional changes in the core.

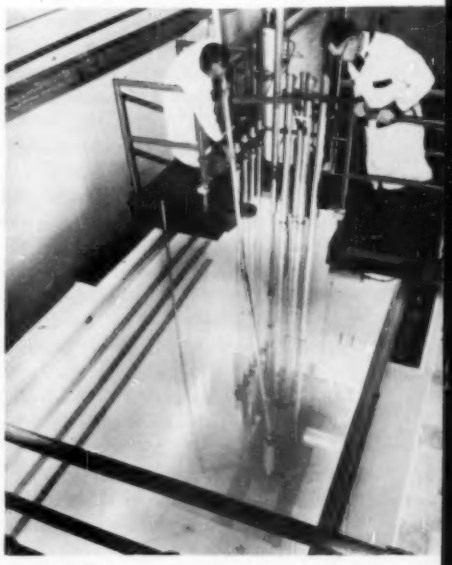
The program might then turn to an investigation of reactivity coefficients. Experimental evaluation of the temperature effects on reactivity generally involves a combination of actual heating of the entire assembly over a limited range and heating of a sample of fuel to an appreciably higher temperature. Some indirect effects, such as density changes, can be simulated by substitution of materials; for example, Styrofoam or organic materials can be used to mock up the reduced density of water at high temperature. The magnitude of other reactivity effects occurring during operation of a power reactor, such as fuel burnup, fission-product production (particularly Sm^{149} and Xe^{135}), and formation of various plutonium isotopes, is normally calculated.

Next the critical experimenter's attention may turn to evaluating control-rod effectiveness. The cold, clean critical is loaded with rods of the proper composition, number, size, shape and location to give the required reactivity margin. The rods are generally added individually or in symmetric groups and the system restored to criticality after each addition. The selection of rods is also influenced by considerations of heat removal so that the determination of power-production patterns is an important part of this stage of the program.

Zero-power experiments. The measurement of detailed flux-distribution patterns for various rod configurations expected throughout the core life is carried out in the zero-power system. Since zero-power experiments may use assemblies of the actual fuel elements and control rods or perhaps the actual core itself (see p. 53), they are well suited for locating possible hot spots. Distributed neutron absorbers are introduced to permit the various rod positions anticipated in actual power operation, and differential calibration curves for the rods are obtained during the course of the flux-mapping program. Flux flattening by nonuniform distribution of fuel can also be investigated at this time.

Other important information that can be obtained from critical-assembly measurements includes:

- The interrelation between the location and strength of the startup source and the location and sensitivity of the instruments for control.



ASSEMBLING an experimental core in Babcock & Wilcox's pool-type facility

- Measurement of neutron and gamma radiation intensities to determine the effectiveness and heating of the shield.
- Neutron economy (conversion or breeding ratio).

The extensive manipulation of the components in a critical assembly requires that the induced activity be kept low. Moreover the materials and design generally preclude operation at very high temperatures. Consequently, critical experiments are not used for investigation of effects requiring high neutron fluxes and/or high temperatures. Thus a program of critical experiments gives no information on heat transfer, radiation damage or kinetic behavior at high power density.

2. Critical Facilities for Basic Physics

By H. C. PAXTON, *Los Alamos Scientific Laboratory, Los Alamos, New Mexico*

CRITICAL assemblies that are intended to supply basic reactor physics data are distinguished from their reactor-development counterparts primarily in degree of complexity. The types of measurements—for example, determining critical configurations and observing related neutron and fission characteristics, time behavior and effects of perturbations—cannot differ significantly. Thus the general facility requirements are the same. There must be provision for safe operation without sacrifice of convenience. For satisfactory measurements, assemblies must be reproducible, while reasonably flexible, and instrumentation must be reliable.

The "clean-critical" assembly is the basic source of reactor-physics data, whether the fissionable material is present in solution or slurry, as a lattice, or as a single piece of metal. The object is a complete understanding of elementary assemblies, to serve as a springboard for the design of practical, more complex reactor systems, either steady power producers or nuclear explosives, or to provide nuclear safety guidance.

A complete experimental survey of a certain class of clean criticals involves an overwhelming number of parameters; these describe such things as the nature and distribution of the fissionable materials, moderators and other diluents, and the type, thickness and shape of the reflector. In practice, experimental surveys are limited in scope and depend upon parallel computing programs to complete the survey by means of interpolation and extrapolation. Indeed, computing schemes are potentially so valuable for reactor design and for filling in basic nuclear safety data that verifying them and providing input parameters for them have become major preoccupations of critical-assembly organizations.

Although the same critical facility can be used for all types of basic physics measurements, one can distinguish three major categories:

Critical surveys. There is no question that the simplified analytical schemes—such as diffusion theory for thermal reactors and the extrapolated-end-point method for fast systems—are the work horses of reactor design. However, these schemes depend for their success on the proper choice of certain parameters (e.g., Fermi age, resonance escape, etc.) that are best obtained from critical surveys of simple geometries.

Experimental critical-mass surveys useful for this purpose are illustrated by compilations intended for nuclear safety guidance. Even more pertinent to reactor development are moderated lattices of fissionable material, which are customarily interpreted in terms of simplified calculations. In this class

"JEZEBEL," a bare Pu sphere, is typical of "simple-geometry" critical assemblies used at Los Alamos to accumulate physics data

are the Brookhaven and Westinghouse water-moderated lattices of slightly enriched uranium and the Argonne heavy-water moderated lattices of U^{235} and various diluents.

Generally, assemblies for this purpose should have a simple unambiguous description at critical, instrumentation for measuring neutron multiplication during approach to critical, and instrumentation for period measurement to calibrate controls so that correction can be made for their influence.

Detailed computation checks. Simple critical-mass data are insufficient to verify detailed analytical schemes such as multigroup, transport or Monte Carlo programs; these schemes and their input data require checking against all available properties of clean critical assemblies before they are ready for use with practical reactors.

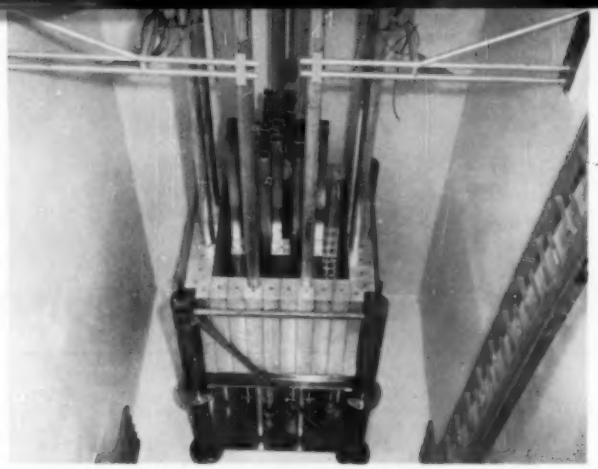
Some satisfying confirmations of detailed calculations, for instance, have been made for the S_n transport method by observing the properties of simple fast-neutron assemblies of U^{235}, Pu^{239}, and U^{233} metal.

In addition to requirements stated earlier for good critical-mass data, assemblies for checking detailed computations must provide internal neutron detectors to map flux and neutron spectra. Other useful measurements such as the Rossi alpha, pulsed-source data and the reactivity effects of changes in core density make further demands on the assembly and its instrumentation.

Input-parameter measurements. Frequently reactor-calculation parameters may best be had by direct observation on clean critical assemblies. Usually the critical system is modified so that the resulting change in critical conditions is a measure of the parameter in question. For instance ORNL measured η for U^{233} by comparing critical dilute aqueous solutions of U^{233} and U^{235} in spherical containers of the same size.

Since the ratio of the just-critical fuel concentrations depends primarily upon $\eta(U^{233})$, $\eta(U^{235})$ and the thermal-absorption cross sections of U^{233}, U^{235}, and H, $\eta(U^{233})$ could be obtained in terms of the other better-known parameters.

Occasionally the critical facility will be used solely as a radiation source for an input-parameter experiment in much the same way as a test reactor is used to feed a thermal column. Thus the radiation may be studied on one day as an important property of the assembly, then used the next day for effects measurements. An example is, first, measurement of the spectrum of leakage neutrons from Godiva (the bare U^{235} metal assembly) and, next, application of the neutrons to biological measurements. Similarly, the study of dynamic behavior of Godiva through prompt critical led to its use as a pulsed neutron source.



NEW TREND has been introduced by Engineering Test Reactor Critical Facility shown here. ETRC will be retained as permanent part of ETR operation to check out proposed test-reactor runs

3. Critical Facilities Tomorrow

CRITICAL FACILITIES are slated to become more rather than less important in the affairs of the reactor designer. As a means of turning out specific design information the critical experiment is proving superior to its rival, the multigroup computing-machine program. Outstanding reactor theorists such as B. Spinrad of Argonne and M. C. Edlund of Babcock & Wilcox state quite frankly that, compared with detailed theoretical calculations, the reactor design information from critical facilities is cheaper and more accurate and takes less time to get.

To date most of the critical experiments supporting prototype reactor designs have been done in the national laboratories. The future should see private industry take over the greatest part of the task of developing specific design information of this kind; this will leave the national laboratories free to concentrate on more fundamental research.

In using critical facilities for reactor design the industry will very likely adopt the strategy used for the Army Package Power Reactor (APPR). Here critical experiments were performed in two distinct phases: First a highly flexible arrangement was used (at ORNL) to establish "ball-park" estimates for the critical mass and the reactivity available for control and shim. With this information the fuel-element design was frozen and a set of elements fabricated. These elements were assembled together with the actual APPR-1 core support structure and control-rod drives to form a "zero-power" experiment in Alco Products' critical facility (see p. 53). This second step gave refined figures for the critical loading and allowed optimization of core performance.

For the ball-park phase of critical experimentation future private reactor designers will need all-purpose facilities flexible enough to mock up a wide variety of concepts; eventually these will include advanced design concepts operating at extreme temperatures and heat flux. Larger concerns will find it profitable to operate their own flexible facilities. Others, who cannot justify full-time use of a facility, will look to organizations like Battelle Memorial Institute, Nuclear Development Corp. of America (NDA) and Alco Products, which are in the business of hiring out critical-facility services.

The second-stage zero-power experiments will be much more an individual problem for each reactor. These experiments may very well be carried out in the reactor vessel itself using as much of the actual core structure as can be safely frozen. (This has already been done with EBWR; see NUCLEONICS July '57, 62.) Preferably the tests would be conducted at temperatures and pressures close to the design conditions. Since no heat flux is involved, fuel elements at this stage would not have to be real working models but only reasonably exact facsimiles; much of the fabrication expense could be saved by omitting welds and using looser tolerances for the mock-up elements.

Another problem that is just beginning to be studied is that of determining core characteristics at very high burnup and for recycled fuel. Zero-power-type experiments will probably be used to get this information; facsimile fuel elements containing radioactive fuel and fission products may be necessary.

Beyond the area of reactor design, critical facilities will find new applications as auxiliary facilities supporting routine reactor operations. Perhaps the first example of this is the Engineering Test Reactor critical facility (see figure). The ETRC has been retained as a permanent fixture to check out scheduled core loadings for the ETR before putting them in the ETR itself. Similarly every power reactor of the future may well come equipped with a modest on-site critical assembly to be used for routine measurements. These might include double-checking new fuel elements as they arrive from the manufacturer (presumably the manufacturer will have already checked the shipment in his own standard critical assembly), evaluating the reactivity worth of used elements and predicting the effects of modifications in core loading.

Meet the Prophets

The predictions on this page represent NUCLEONICS' summary of a collective crystal-gazing session on the subject of the future of critical facilities attended by Dixon Callihan (ORNL), Joel Chastain (Battelle), M. C. Edlund (B&W), G. A. Linenberger (AGN), John Noakes (Alco), Hugh C. Paxton (Los Alamos), W. C. Redman (Argonne), D. V. Williams (B&W) and Roy Zimmerman (NDA).

NUCLEONICS Survey of

Owner:	Alco	AEC	AEC	AEC	AEC	B&W	AEC[2]	AEC[2]
Designer:	Vitro	ANL	ANL	ANL	ANL	owner	Bettis	Bettis
Location:	Schenectady, N. Y.	NRTS, Idaho	Lemont, Ill.	Lemont, Ill.	Lemont, Ill.	Lynchburg, Va.	Pittsburgh, Pa.	Pittsburgh, Pa.
Name:	none	ZPR-3	ZPR-4'	ZPR-5	ZPR-7	none	TRX	SFR-FA
Startup:	8/26/56	10/20/55	5/31/57	6/28/56	7/3/57	1/15/57	1953	1954
Capital investment:	$300,000	n.a.	n.a.	n.a.	n.a.	$700,000		
Use or operating charge:	$600/day	n.a.	n.a.	n.a.	n.a.	n.a.		
Number of cells:	1	1	1	1	1	3	1	1
Applications—								
basic physics:	—	3	2	2	—	3		
basic reactor physics:	2	2	1	1	2	2		
specific reactor design:	1	1	—	—	1	1		
specific reactor operation & safety:	—	—	—	—	—	—		
Specific reactor designs investigated to date:	APPR-1	EBR-1, EBR-2	—	—	EBWR	Indian Pt., MSR, LMFRE	—	S3W, S4W
Available for hire:	yes	yes[1]	yes[1]	yes[1]	yes[1]	yes		
Materials available—								
fuel:	UO_2-SS	U, Pu	U	U	UO_2, ThO_2	U, Th		
moderator:	H_2O	—	H_2O	H_2O	D_2O	H_2O		
coolant:	—	Al	H_2O	Al	D_2O	H_2O, Bi		
reflector:	H_2O	U	H_2O	H_2O	D_2O	—		
structure:	SS	SS, Zr	Al	SS	Al	—		
control:	—	—	—	—	—	—		
References:	APAE-21	—	ANL-5379	ANL-5547	ANL-5715	—		

Owner:	GE	AEC	AEC[2]	AEC[2]	AEC[2]	AEC[2]	AEC[2]	AEC
Designer:	owner	HAPO	KAPL	KAPL	KAPL	KAPL	KAPL	KAPL
Location:	Pleasanton, Calif.	Richland, Wash.	Schenectady, N. Y.	Schenectady, N. Y.	Schenectady, N. Y.	Schenectady, N. Y.	Schenectady, N. Y.	Schenectady, N. Y.
Name:	none	PCTR	PPA	ATR	PMA	FPR	CWA	PTR
Startup:	9/6/57	10/25/55	1948	1954	1954	1956	1957	4/10/58
Capital investment:	$4,000,000	$250,000						$2,000,000
Use or operating charge:	n.a.	$300/day						n.a.
Number of cells:	2	1	1	1	1	1	1	1
Applications—								
basic physics:	3	4						—
basic reactor physics:	2	2						1
specific reactor design:	1	1						2
specific reactor operation & safety:	—	3						—
Specific reactor designs investigated to date:	Dresden	PRTR	—	SAR	—	SAR	DIG	—
Available for hire:	yes	yes[3]						no
Materials available—								
fuel:	UO_2	U-Al, UO_2-Pb						U
moderator:	H_2O	C						H_2O
coolant:	H_2O	—						H_2O
reflector:	Be	C						H_2O
structure:	Al	C						SS, Zircaloy
control:	boral	Cd-U						B-steel
References:	GEA 6595-2	HW-32791						n.a.

Explanatory Notes

Capital Investment—estimated total investment
Use or operating charge—charge to user in case of commercial facilities; estimated operating cost in case of government facilities; fuel charges not included; day = 8 hr
Applications—what the facility is used for in order of importance
n.a.—not available
Alco—Alco Products, Inc.
A1W—first generation Westinghouse reactor for aircraft carriers
ANL—Argonne National Laboratory (operated by Univ. of Chicago for AEC)
APPR-1—Army Package Power Reactor, Ft. Belvoir, Va.
ARE—Aircraft Reactor Experiment (dismantled)
B&W—The Babcock & Wilcox Co.
Bettis—Bettis Field (operated by Westinghouse Electric Corp. for AEC)
BMI—Battelle Memorial Institute
BNL—Brookhaven National Laboratory (operated by Associated Universities, Inc. for AEC)
BSR—Bulk Shielding Reactor, Oak Ridge, Tenn.
CANEL—Connecticut Aircraft Nuclear Engine Laboratory
CE—Combustion Engineering, Inc.
D1G—first generation General Electric reactor for destroyers
EBR—Experimental Breeder Reactor, NRTS,
EBWR—Experimental Boiling Water Reactor, Lemont, Ill.
ETR—Engineering Test Reactor, NRTS, Idaho
GCRE—Gas Cooled Reactor Experiment, NRTS
GD—General Dynamic Corp., John Jay Hopkins Laboratory
GE—General Electric Co., Vallecitos Atomic Laboratory
GEANP—General Electric Aircraft Nuclear Propulsion
HAPO—Hanford Atomic Products Operation (operated by General Electric Co. for AEC)
KAPL—Knolls Atomic Power Laboratory (operated by General Electric Co. for AEC)

Operating Critical Facilities in the U. S.

AEC[2]	AEC[2]	AEC[2]	AEC[2]	BMI	AEC	CE	CE	GD	AEC	AEC
Bettis	Bettis	Bettis	Bettis	owner	BNL	KAPL	owner	owner	GEANP	GEANP
Pittsburgh, Pa.	Pittsburgh Pa.	Pittsburgh, Pa.	Pittsburgh, Pa.	W. Jefferson, Ohio	Upton, N. Y.	Windsor, Conn.	Windsor, Conn.	San Diego, Calif.	Evendale, Ohio	NRTS, Idaho
PWR-FA	RPF	S5W-FA	A1W-FA	none	none	FCE	ACE	none	none	LPTF
1954	1956	1956	1956	1/2/57	8/15/55	7/16/56	11/27/56	8/15/57	8/30/54	4/11/58
				$500,000	$300,000	n.a.	n.a.	n.a.	$1,700,000	$1,300,000
				$500/day	$5,000/day	n.a.	n.a.	n.a.	n.a.	n.a.
	1	1	2	1	2	1	1	1	2	2
									n.a.	n.a.
				—	—	—	—	—		
				2	1	1	2	2		
				1	2	2	1	1		
				—	3	—	—	—		
Shippingport	—	S5W	A1W	GCRE	MRR, NRR, LMFRE	S1C	S1C	TRIGA	n.a.	n.a.
				yes	no	yes	yes	yes	no	no
									n.a.	n.a.
				U	U	U	U-Zr	U		
				H_2O, Be, C_2H_4	H_2O, C	C_2H_4	H_2O	ZrH		
				Al, C_2H_4	H_2O	C_2H_4	H_2O	—		
				H_2O, Be, C_2H_4	C, H_2O	C_2H_4	H_2O	C		
				SS, Al	Al, SS	Al, Zr	Zr	Zr		
				B_4C, W, Cd	SS, B-steel, Cd	—	—	—		
				TID-4500	—	—	—	—	n.a.	n.a.

USAF	Martin	NDA	AEC	AEC	AEC	AEC[2]	AEC	AEC	USAF	Westinghouse
GE/Lock-heed	owner	owner	ORNL	ORNL	ORNL	ORNL	Phillips	Phillips	CANEL	owner
Dawsonville, Ga.	Baltimore, Md.	Pawling, N. Y.	Oak Ridge, Tenn.	Oak Ridge, Tenn.	Oak Ridge, Tenn.	Oak Ridge, Tenn.	NRTS, Idaho	NRTS, Idaho	Middletown, Conn.	Waltz Mill, Pa.
CER	none	NDA-CX	West	East	South	PCA	RMF	ETRC	none	WREC
6/9/58	12/10/57	1/22/58	12/20/50	2/4/51	3/20/58	1958	2/11/55	5/20/57	3/12/58	12/8/57
n.a.	$400,000	n.a.	$400,000	$500,000[6]	$300,000		n.a.	$398,000	n.a.	$450,000
n.a.	$700/day	n.a.	$600/day	$600/day	$600/day		$500/day	$500/day	n.a.	$800–1,200/day
1	2	2	1	1	1	1	1	1	2	2
—	—	4	3	3	2		2	—	—	—
—	2	3	2	2	1		1	2	2	2
1	1	1	4	1	4		—	1	1	1
—	—	2	1	4	3		—	3	—	—
RER	APPR-1	PRR	APPR-1, BSR-2	ARE	—	ORR	—	ETR	n.a.	Yankee, WTR
yes[4]	yes n.a.	yes	yes[5]	yes[5]	yes[5]		yes	yes[7]	no n.a.	yes
U-A1		U-A1	U, $UO_2(NO_3)_2$, UO_2F_2	U, UF_4	U, $UO_2(NO_3)_2$, UO_2F_2, U-A1		U	U		U
H_2O		D_2O, C, H_2O	H_2O	Be, C, C_2H_4	H_2O, D_2O		H_2O	H_2O		H_2O, D_2O
H_2O		D_2O, H_2O	—	—	—		H_2O	H_2O		H_2O, D_2O
H_2O		C, D_2O	H_2O	Be, C, C_2H_4	H_2O, D_2O		H_2O	Be, BeO		—
Al		Al	—	SS, Al	—		Al, SS	Al, SS		SS, Al
Cd		Cd	—	—	—		Cd, B_4C	B, Ni, Cd		—
LAC-143	MND-1157	NDA-3002	—	NEPA-1769	—		IDO-16108	IDO-16332	n.a.	WCAP-311

LMFRE—Liquid Metal Fueled Reactor Experiment
Lockheed—Lockheed Aircraft Corp.
Martin—The Martin Co. (formerly The Glenn L. Martin Co.)
MRR—Medical Research Reactor, Upton, N. Y.
MSR—Merchant Ship Reactor, N8 *Savannah*
NDA—Nuclear Development Corp. of America
NRR—Naval Research Reactor, Washington, D. C.
NRTS—National Reactor Testing Station
ORNL—Oak Ridge National Laboratory (operated by Union Carbide Nuclear Co.)
Phillips—Phillips Petroleum Co.
PRR—Pawling Research Reactor, Pawling, N. Y.
PRTR—Plutonium Recycle Test Reactor, Richland, Wash.
SAR—Submarine Advanced Reactor, West Milton, N. Y. and USS *Triton*
S1C—first generation Combustion Engineering reactor for submarines
S3W, S4W, S5W—third, fourth, fifth generation Westinghouse reactor for submarines
Vitro—Vitro Engineering Co. Div., Vitro Corp. of America
WTR—Westinghouse Test Reactor, Waltz Mill, Pa.

Footnotes

[1] There have been at least two cases in the past, and another pending, in which Argonne's critical facilities have been made available under special circumstances.
[2] Although these facilities are listed as "unclassified" in the "Twenty-fourth Semiannual Report" of the AEC, NUCLEONICS was unable to get further details from the contractor or AEC.
[3] This facility may be available for use in connection with AEC or other governmental programs.
[4] U. S. Air Force permission required.
[5] Possibly.
[6] Plus ~ $1,000,000 for Be.
[7] It is available to experiment sponsors (in ETR) for the purpose of deriving data from testing of prototypes of their experiments.

High-Temperature Critical Facility

The first of its kind in the world, this facility can operate at up to 550° F and 1,250 psi, thus aiding more accurate design of pressurized-water reactors

By J. A. BISTLINE
and C. S. HOFMANN
Knolls Atomic Power Laboratory
Schenectady, New York

THE EXTRAPOLATION of critical mass, temperature coefficients, control-rod worth, water-gap peaking, etc., from room-temperature experiments to power-reactor operating temperatures is uncertain at best. To provide more accurate design data in the operating range of power reactors, the Knolls Atomic Power Laboratory has placed in operation a unique critical facility, the Proof Test Reactor (PTR). It combines, for the first time, the flexibility of a critical assembly with the operating temperatures and pressures found in power reactors.

The design of the PTR raised many problems not usually associated with critical facilities, and their solution, as a consequence, has provided many special features. Some of them are:

- The pressure-vessel head is fixed and the core is enclosed by raising the vessel with a hydraulic lift. This permits a controlled, safe rate of immersion of the core because the vessel can be filled with water prior to raising.
- The core and all components inside the vessel are supported from the fixed head. This provides easy access to the top and sides of the core. Also, the bottom of the core is at floor level, and workers can step right in when the vessel is lowered. By adjusting fuel and zircaloy strips, the metal-to-water ratio can be varied from 1:1.4 to 1:0.46.
- The mechanically sealed pressure vessel can be quickly opened or closed.

PTR Design Details

PRIMARY WATER SYSTEM Closed-loop system supplies constant-temperature water that is piped through vessel head to below core, exits through head. Loop consists of circulation pumps, steam-to-water heat exchanger, electrical resistance heaters, water-to-air heat exchanger and pressurizer. Materials of construction are 316 stainless steel and carbon steel clad with 304 stainless. Design pressure was 1,500 psi; design temperature was 650° F.

AUXILIARY WATER SYSTEM Makeup water for primary system is provided by loop consisting of hold tank, ion-exchange columns (not shown), fill pumps, test pump, sump pump (not shown) and emergency blowdown tank (not shown). Hold tank has 4,500-gal capacity(~ 1½ times system capacity); mixed-bed ion exchangers provide 4,500-gal of 0.5-megohm water.

PRESSURE VESSEL 60-in.-i.d. (nominal) vessel is raised or lowered with respect to fixed head by hydraulic lift of 30,000-lb capacity. Pressure loading of ~ 5×10^6 lb is taken by 32 "I" clamps that hold vessel and flange to head. Seal is provided by compression gasket and chevron-type packing gland. Head is flat forging of 304 stainless, 17 in. thick, having penetrations for nineteen control-rod drives, six instrumentation thimbles, three thermocouple clusters, two source tubes, inlet and outlet water lines, liquid-level probe and resistance thermometer. Head is supported by four 10 x 10-in. "H" columns anchored in concrete foundation.

CORE 8 x 32 x 30-in. active core is made up of 2 x 4 x 40-in. zircaloy boxes held together by zirconium bands. Each box has adjustable spacer plates into which fuel or zircaloy filler strips are inserted. Fuel is 93% U^{235} strips, 0.0013 in. thick, clad with 0.010 in. of zircaloy (max fuel density is 3.4 gm in^3). Zircaloy filler strips are available in 0.039- and 0.023-in. thicknesses. Burnable poison is provided by stainless strips containing 0.5% natural boron. Fuel, filler and poison strips are interchangeable. Control rods are 1.5% B^{10} in stainless blades 0.125 in. thick, 3.5 in. wide and 40 in. long.

Gasket compression bolts can be tightened in ½ hr using air-driven torque wrenches. Experience has shown that the vessel can be opened and lowered within 20 min of the time that the system is cooled to 120° F (minimum cooldown time, 2 hr 40 min).

• The use of both steam and electricity for heating the primary water minimizes the heating-cycle time (heatup time, 5 hr). Boiling in the system is prevented by maintaining a 100-lb overpressure with additional heat in the pressurizer.

• The control system provides for automatic, programmed operation (each of the input variables also has a manual override). Operating experience has shown that the automatic control is successful (temperature regulation at steady state is $\pm 0.3°$ F).

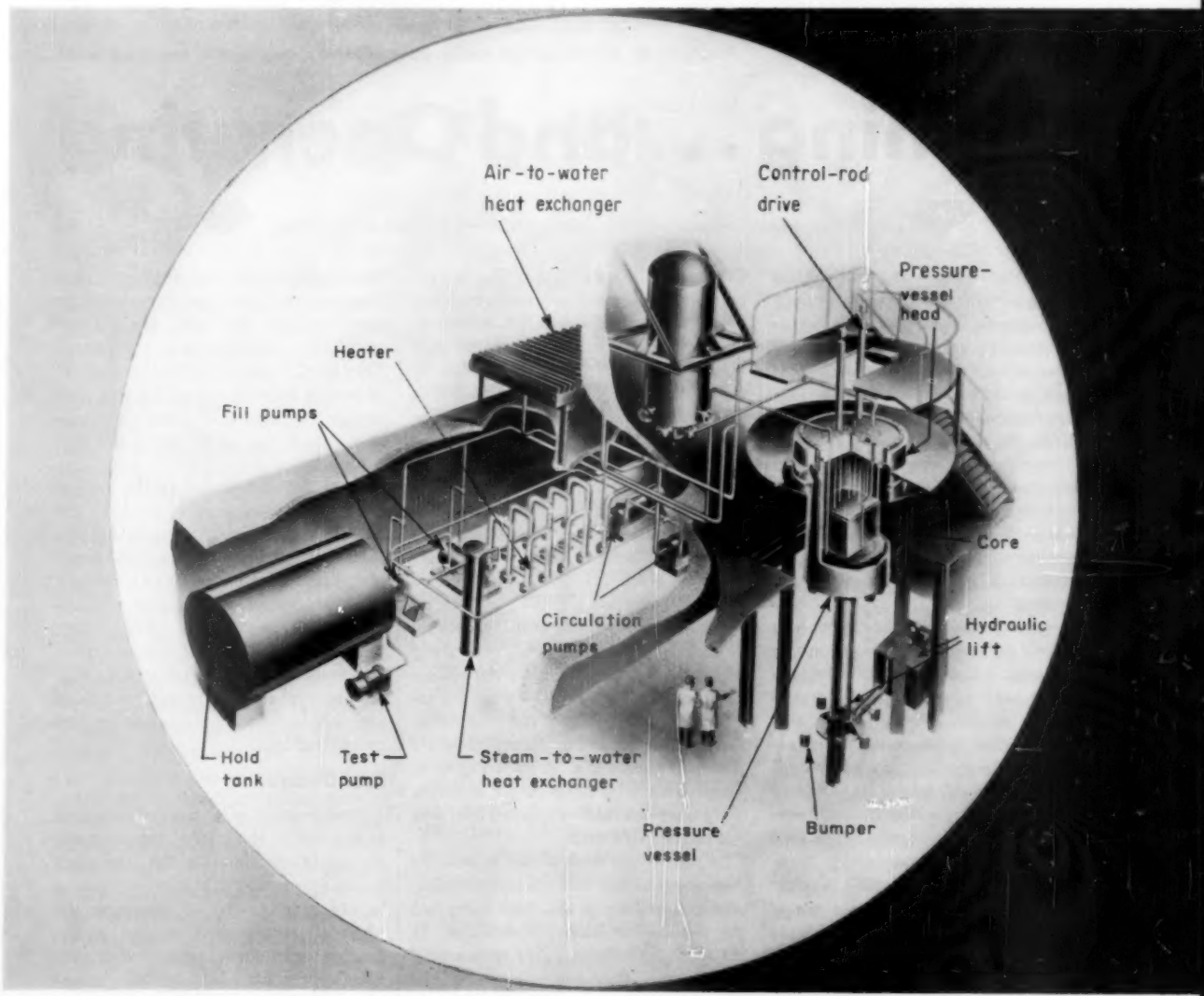
• BF_3 chambers and counters were developed for operation at up to 550° F.

• Flux measurements in the PTR are made with gold and P-metal (20% Ni, 80% Mn) foils and by clad U^{235} elements because most of the usual neutron-detecting foils used in critical facilities are adversely affected by the high temperatures and corrosion rates.

• An unloading machine is provided that can remove core materials during operation of the PTR.

Experimental Program

The initial experimental program will provide information on the following parameters as a function of temperature from 100 to 550° F: critical mass, temperature coefficients, scattering properties of metals, control-rod worths, water-gap peaking and diffusion-length measurements. The core sizes to be investigated are 32- by 30-in. slabs, 8, 14 and 24 in. thick, with water-to-metal ratios of 1:1.5 and water and steel/water reflectors on two 30- by 32-in. sides. The steel/water reflectors will vary from 20/80 to 70/30. The 8-in.-thick water-reflected core will accentuate the leakage effects, and the 24-in. core will be more sensitive to k_∞. The 14-in. core will provide an intermediate check.



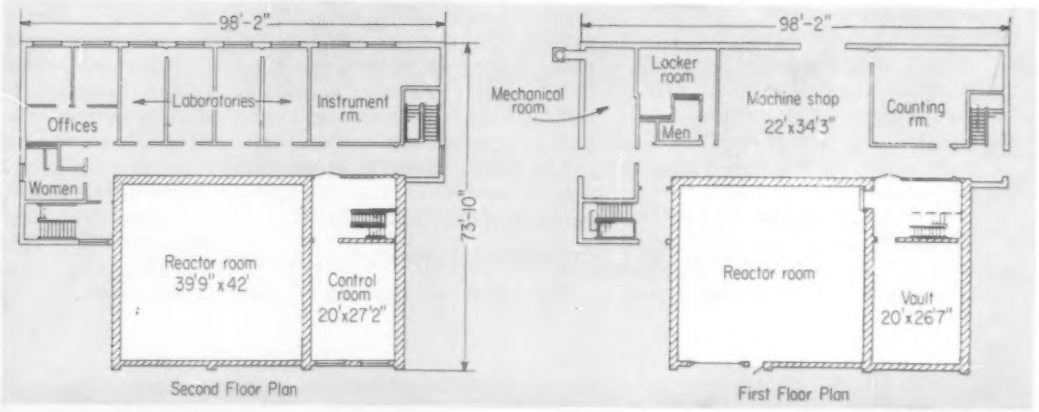


FIG. 1. Floor plan for Battelle Critical Facility shows efficient arrangement of component areas

Planning . . . and Operating

Site Selection. *Hazards protection is a prime consideration in site selection for a critical-assembly laboratory. The potential hazards are considerably less than for a power reactor since only the fission-product activity produced during the power excursion itself is significant. However, the flexibility and the variety of experiments performed may lead to a higher probability of having an accident. Also critical assemblies are always operated at such a low power that self-regulating characteristics are never in operation until a power excursion is well under way.*

Complete containment has never been considered necessary for critical-assembly experiments. Rather the exclusion-area approach has been used to provide protection from possible critical-facility hazards. An area large enough to reduce the radiation doses from a credible accident to a manageable level at the boundary is likely to be cheaper than complete containment and the extra space can be used for other laboratory purposes.

As an example, the Battelle Nuclear Research Center is located on a site of about 500 acres of farm land with the facility located 1,200 ft away from the nearest boundary.

Critical-Facility Building. *The key requirement for the critical-facility building is that it be versatile enough to accommodate any critical-assembly project that may arise. A typical floor plan is shown in Fig. 1. The assembly room is 40 ft by 40 ft by 50 ft high. This floor area is large enough to permit operation of two critical-assembly projects concurrently with sufficient room for unloading trucks and performing various assembly and test operations. The 50-ft ceiling height permits the construction and operation of mock-ups of the large water-moderated reactors.*

The critical-assembly-room floor should be designed for a load-bearing capacity of at least 1,000 lb/ft². Since critical assemblies in general have no shielding except for self-shielding of core and reflectors, shielding must be furnished by the assembly-room walls. Two feet of reinforced concrete is sufficient for shielding purposes provided the operating level does not exceed ~20 watts.

A fuel-storage vault should be provided having a steel door with a secure combination lock and a cage door with a key lock for use during loading operations. A 20 × 27-ft vault can safely store several

Continued on page 50 (top)

Once a critical-experiment program has been mapped out the experimenters must as their first step begin three essentially simultaneous operations. They must design the critical assembly, prepare a hazards report for this particular assembly and order the long-lead-time items, particularly the fuel materials.

Some detailed design of the critical assembly is necessary to analyze the hazards associated with operating the assembly; at the same time the results of the hazards analysis may indicate a need for additional refinement or modification in the design. The design must include a choice of fuel and other core materials in a form that will simulate, nuclearwise, the prototype reactor and will be relatively inexpensive and quite flexible.

Fuel Design

Specifically, the form and dimensions of the fuel in the critical assembly are chosen (a) to simulate the important nuclear properties of the fuel form used in the reactor, (b) to duplicate the physical arrangement of fuel in the reactor under study, (c) to permit variations in the basic loading and configu-

its extensive experience in . . .

FIG. 2. Vertical stands (l.) are used for liquid-moderated systems, horizontal stands (r.) for solid systems

a Critical Facility

By F. J. JANKOWSKI and J. W. CHASTAIN, *Battelle Memorial Institute, Columbus, Ohio*

ration while maintaining a fairly uniform core, and (d) to maintain certain health and safety requirements in fuel handling and assembly operation.

Frequently, thin strips of highly enriched uranium can be used with metal tubes or plates to mock up a fuel element. Slightly enriched alloy systems can be mocked up with thin strips of highly enriched uranium together with plates of natural uranium or a uranium alloy. Some reactor fuels cannot easily be duplicated; e.g., there seems to be no way to simulate uranium dioxide of low enrichment except to press buttons of uranium dioxide.

After working out the core design, a request is submitted to the AEC for a uranium allotment large enough to cover scrap and losses during fuel fabrication. The uranium can be obtained directly from Oak Ridge as uranium hexafluoride but if uranium oxide or metal is required there is an extra charge for this conversion. If the fuel is to be used as foil, it is the responsibility of the user to arrange and pay for the fabrication into the desired form and for the eventual conversion of the material, including the scrap, back to uranium hexafluoride.

Hazards Review

The Hazards Summary Report, required for each critical-assembly project, is concerned with hazards to both the public and the operating staff. The hazards should be evaluated for normal operations as well as for a "maximum credible accident." The individual report required for each new assembly ensures that the potential hazards of the new assembly do not exceed the design limitations of the facility as set forth in the initial report covering the facility and general mode of operation.

In addition to the AEC review, an internal review of hazards and procedures by a responsible committee is beneficial. The committee should meet prior to critical operations to discuss the assembly, its operations, and the procedures to be used. This committee also can be called upon to evaluate and comment on special experimental procedures, particular phases of the work, or particular equipment proposed for use in experiments.

Assembly Preparation

While the Hazards Summary Report is being prepared or is under consideration by the AEC, and while the fuel materials are being ordered and fabricated, the work of constructing the critical assembly can proceed. After the construction has been completed, a period of time must be devoted to checking out all instrumentation, interlocks, rod drives, limit switches, etc.

Once the assembly is checked out, a simulated approach to critical is made without fuel in the core. This follows exactly the procedure planned for the critical operations including the use of the neutron startup source and the taking of all the data which will be taken later. This serves to familiarize the crew with the equipment and the operating procedures and shows any weaknesses in either equipment or procedures.

After the operational procedures and the performance of the equipment are found to be satisfactory, the actual critical-assembly experiments can be started. The preparation for the experiments, such as preparing and mounting foils, modifying fuel elements, interchanging control rods, and reducing and analyzing data takes at least as much time as the actual per-

Continued on page 50 (bottom)

Planning . . .

hundred kilograms of enriched-uranium foil. Ideally the control room, assembly room, and vault area should be arranged so they can be shut off from the remainder of the building to form an inner exclusion area.

Experimental Equipment. *The requirements of versatility and utility should be carried over into the design and construction of the experimental equipment if a number of experiments are anticipated. Certain items for handling a large range of critical-a embly projects can be made available as permanent laboratory equipment if sufficient thought is put into the design. With such equipment a critical assembly can be put into operation in a minimum time and for a minimum cost. One assembly was made critical at Battelle approximately 10 weeks after start of the work.*

A typical control system includes three neutron-detecting ionization chambers, one scintillation-crystal–photomultiplier-tube combination used as a d-c device, a fission counter and a BF_3 counter. The two pulse counters are used only as information channels while the four d-c devices are used for control and operation. Frequently, two of the ion chambers have logarithmic outputs, which are differentiated to give period information in addition to log power level. This instrumentation provides three neutron levels, one gamma level and two period signals; each of these six signals can cause a reactor scram if a preset level is exceeded.

A number of interlocks are incorporated in the control system to help ensure that the proper sequence of operations is followed.

For a startup source a small polonium-beryllium neutron source can be attached to the end of a flexible cable that is pushed through a tube into the core by a remote drive.

The majority of experiments can be handled with two flexible reactor-assembly stands, one horizontal, the other vertical. The horizontal stand has one table fixed and the other movable (see Fig. 2). Dry- or solid-moderated assemblies are constructed in two halves and moved together remotely for the critical-assembly experiments. This assembly stand, provided with overhead supports and space beneath the table, can use vertical rod drives either above or below the core or horizontal rod drives—an arrangement that gives considerable versatility.

A vertical assembly stand is useful in research on liquid-moderated systems (see Fig. 2). This type of stand has a low level to support the reactor tank, an intermediate level to provide a working area around the core, and a top deck for supporting the control-rod drives. The lowest level of the stand shown in Fig. 2 is 7 ft off the floor to permit gravity drainage of liquid moderators into storage tanks on the floor.

Counting of activated materials can be handled adequately with three counting channels used interchangeably with scintillation heads, G-M tubes or gas-flow counters. An automatic sample changer will speed up counting. Indium, gold and uranium foils and uranium used with aluminum catcher foils are the most common.

Operating Staff. *A typical staff size is seven professional people, generally physicists, and four technicians devoting full effort to the critical-assembly work. A minimum of three professionals is considered necessary to conduct the majority of critical-assembly projects efficiently.*

Operating . . .

formance of the experiment. Thus, a minimum staff of three physicists can keep a critical assembly operating approximately half time averaged over a long period.

Operating Rules

The critical experiments are governed by the procedures and limitations specified in the Hazards Summary Report, and by critical-assembly operational and laboratory rules established by the laboratory. Typical operational rules are (a) there must be a minimum of three power-level scrams and one period scram in operation for all critical experiments, (b) the assembly must be built and adjusted so that reactivity cannot be added at greater than a predetermined rate, and (c) a minimum of a specified amount of shutdown control will be available in the critical condition at all times.

The laboratory rules are concerned with the noncritical operations and specify the conditions under which the laboratory may be used and conditions under which certain work may be conducted. These rules may include such things as: No one is to be in the assembly room when water is added to a reactor tank or when reactor halves are assembled. Consequently, if water must be pumped or the tables run together to check out equipment it must be done remotely or else all fuel must be removed from the assembly and stored in the vault prior to the test. Another laboratory rule at Battelle requires that at least two physicists familiar with the operation of the critical assembly be in the control room during criticality.

Complete records are kept of the uranium received showing exactly where each quantity is at a given time. This is needed for accountability purposes, to be sure all material is present, that none is lost in handling, and to give an accurate value of the fuel material in the core.

AEC Regulations for Critical Facilities

To construct a privately owned critical-assembly building the owner must first secure a building permit from the AEC. The application for this permit must be accompanied by a hazards summary report that fully describes the site, the surrounding area, the building planned for the site, the possible reactor designs and their instrumentation, the types of experiments, the safety features for the experiments, and the hazards to the surrounding area resulting from an assumed accident.

To operate the critical facility the owner must obtain a license to possess special nuclear material and a license to operate the facility. The application for the first of these must include a "procedures manual" giving general information on the storage, accounting, security, and safety provisions that will be followed at the facility in handling special nuclear materials.

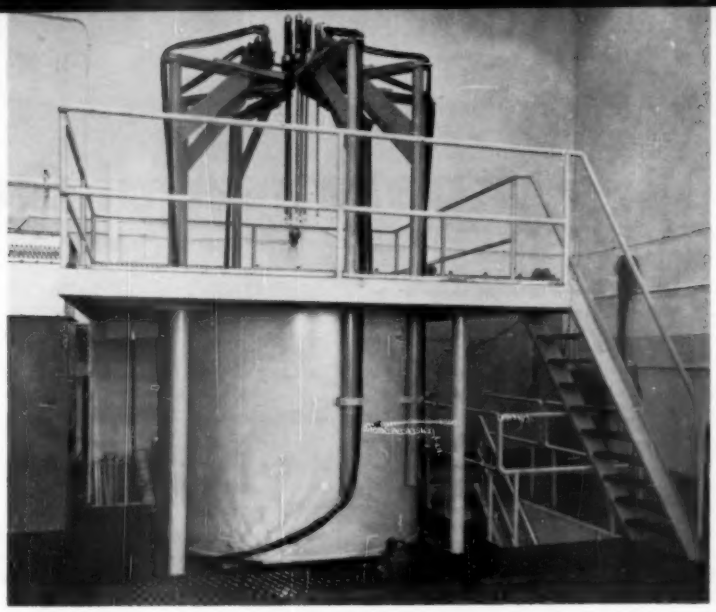


FIG. 1. Tank-type critical facility used at Alco for APPR-1 zero-power experiments

A Sample Critical Facility Program—

The APPR Zero-Power Experiments

By JOHN W. NOAKS, *Alco Products, Inc., Schenectady, New York*

THE PRINCIPAL objectives of the APPR zero-power experiments were determination of the reactor's operating characteristics and potential productive lifetime. Additional objectives stressed improvements in operating efficiency and reliability. The principal objectives were realized in a series of five experiments designated as ZPE-1 and described on the following page. ZPE-1 was followed by ZPE-2, a series of experiments directed toward improving the core design; experiment number 6 on the page following is an example of the experiments in this series.

Critical Experiment or Zero-Power Experiment?

The history of APPR offers a good example of the difference between critical experiments and zero-power experiments. The original "critical experiments" for APPR-1* were carried out by Oak Ridge on one of the flexible assemblies available at its critical facility (*1*, *2*). This series of experiments firmed up basic core parameters, such as critical mass and reactivity allotment for control and shim, to the point that the fuel elements could be designed and fabricated.

Alco Products then conducted a series of "zero-power" experiments at its critical facility on an assembly composed of the fabricated elements and the actual APPR-1 core-support structure and control-rod drives. These experiments on the "completed core" gave final values for the mass, rod worths and temperature coefficients as well as other detailed information (see page following) that helped in the design of remaining parts of the reactor system.

* For description of APPR-1 see Reactor Foldout, NU, Aug. '57, 60.

Experimental Assembly

The APPR-1 zero-power experiments were conducted within the 2,500-gal reactor tank shown in Fig. 1. The tank is filled with water by pump from a sump tank below floor level and empties on demand via a 6-in. valved dump line. The 84-in.-dia reactor tank includes a 27½-in.-dia and 65-in.-deep lower extension hung from the tank floor. This extension has lateral ports serving as mounts for the APPR-1 control-rod drives. The core support, a honeycomb structure providing sup-

Continued on page 54

The APPR Zero-Power Program—

Experimental Questions and

1. What is the critical mass as a function of control-rod position for the clean core at 68° F?

The BF_3 and U^{235}-lined chambers and the associated amplifiers, scalers, and count-rate meters were used for the startup operation. The reactor tank was flooded and background and Po-Be source count rates determined. First, the critical mass with control rods fully withdrawn was measured by plotting the reciprocal of source multiplication, as a function of uranium added. The control-rod fuel elements and absorbers were the first to be added to provide safety during succeeding additions. As each fuel increment was added to the core, the control rods were withdrawn and a source multiplication determined. Figure 2 predicted by this method a critical mass corresponding to approximately 17 elements. Further additions of fuel elements resulted in a decrease in control rod withdrawal. Since the APPR-1 was to be operated with the two inside eccentric rods (designated A and B) fully withdrawn, and the remaining five rods operated as a bank, the core was built up from the critical 17 elements to the normal loading of 45 elements compensated by the five-rod bank. The 45-element APPR-1 core was critical at 68° F with a five-rod bank setting of 3.73 inches withdrawal and rods A and B fully withdrawn. In general terms, the temperature coefficient was determined by calibrating a control rod by the period method and plotting both the critical control-rod positions and the moderator temperature (by recording thermocouples) as a function of time.

2. Does the temperature coefficient of reactivity between 68° and 180° F satisfy the design criterion for control by temperature coefficient?

Working with the fresh-water moderator presented something of a problem. As the water temperature was increased, by means of several 15 kva immersion heaters, air bubbles deposited along the plate surfaces and resulted in an apparently severe negative reactivity effect. Subsequent release of these accumulated bubbles caused the rather unsightly bump shown in Fig. 3. Deaeration of the moderator resulted in more realistic values.

The temperature coefficient was determined at approximately 5° F intervals using the relation:

$$\frac{\partial \rho}{\partial T} = \frac{\partial \rho}{\partial x} \cdot \frac{\partial x}{\partial t} \cdot \frac{\partial t}{\partial T}$$

where:

$\partial \rho / \partial x$ = control rod calibration in cents per inch.

$\partial x / \partial t$ = control rod motion in inches per minute.

$\partial t / \partial T$ = reciprocal heating rate in minutes per °F.

3. Is there enough excess reactivity to override temperature, equilibrium xenon, and provide an adequate lifetime?

To provide an experimental basis for analytical prediction of core life, the core excess reactivity was determined by calibrating the five-rod bank as a function of withdrawal from the core. The boron-steel strips were distributed uniformly throughout the core to permit the bank withdrawal. Figure 4 describes the bank position in terms of the B^{10} content of the strips added. (Weight of contained B^{10} was taken as 0.1739 per gram of natural boron.) Calibration of the five-rod bank was taken at a number of points (Fig. 4) and the integral of the resulting curve yielded an excess k of about 16.6%. To convert this integral of the reactivity worth curve $\Delta k_{eff} = \int \frac{\partial \rho}{\partial x} dx$ to the common analytical integral expression for reactivity, the relationship (7) $\rho = 1 - e^{-\Delta k_{eff}}$ was used where ρ has the significance of a hypothetical reactivity that would result if the total reactivity change could be measured by simply withdrawing the rods in one step. Applying this expression, the resultant ρ was 15.4%. Another school of thought contends that the measured integral is in itself the quantity ρ.

4. Can the reactor be shut down if some of its rods become stuck?

A requirement that the APPR-1 be capable of shutdown in its most reactive state (partial boron burnout and 68° F) by 80% of its control rods prompted this experiment. The reactor was taken critical on various combinations of rods (the so-called "stuck rod" combinations) and these values tabulated (see table). The interpretation (*8*) of the data indicated that this condition was met.

5. Does the power distribution for the most adverse normal operating condition satisfy the criterion for no local boiling?

One major design feature of the APPR-1 not yet finalized at the time of the ZPE-1 series was the orifice plate on the inlet side of the core. Clearly, the design for properly orificed flow was contingent upon a knowledge of the relative power production in each element and the location of severe local power peaks as a function of core life. The gross longitudinal power distributions, as seen by bare gold, were determined for a sufficient number of elements to define average distributions for all core elements. To provide a more accurate picture of the power distributions at operating temperature (about 450° F), the analytically predicted bank withdrawal of 6.3 inches at this temperature was provided by the distribution of a few boron steel strips throughout the core. Care was taken to ensure reasonable spacing between the gold foils and the distributed boron steel to minimize artificial effects. Figure 5 describes the resulting measurements which formed the basis for APPR-1 flow control.

Critical Rod Arrangements

	Rod positions (inches withdrawn)						
Rod combination	*1*	*2*	*3*	*4*	*A*	*B*	*C*
1	22.0	0	0	0	9.5	0	0
2	22.0	10.09	0	0	0	0	0
3	11.97	0	0	0	22.0	0	0
4	0	0	22.0	0	0	0	13.87
5	22.0	0	0	15.06	0	0	0
6	0	0	16.21	0	0	0	22.0
7	3.36	0	0	0	22.0	0	22.0
8	0	0	9.84	0	22.0	22.0	0
9	0	0	0	0	22.0	22.0	9.98

Answers

Attempts to understand fine structure of the thermal neutron flux led to remarkable agreement between the P_3 analysis (*5*) and the flux measurements.

As the numerous flux measurements progressed, a suspected source of flux peaking in the water hole between the control-rod fuel and absorber sections, in fact, proved to be more severe than expected. In terms of the peak-to-average (P/A) bare-gold flux of 2.3 for the core as a whole (with the five rod bank withdrawn to 6.3 inches), the P/A in the central control rod was 4.0. Clearly this severe peaking would cause local boiling, at the leading edge of the control-rod fuel element, in transient if not in steady state. To alleviate this condition comb-like structures of Haynes alloy 25 were inserted perpendicular to the planes of the fuel plates.

Subsequent flux tests with various numbers of combs led to the fabrication of permanent combs for the APPR-1 control rods. To date there have been no indications of flux peaking difficulty.

6. Will steel reflectors improve the core performance?

There is reason to believe that a stainless steel reflector might give increased core reactivity and reduced core-reflector interface flux peaking. The APPR-1 core presents two pairs of side faces. One pair of faces is in a plane perpendicular to the plane of the fuel plates (and therefore parallel to the supporting fuel-element side plates) and the other pair of faces is parallel to the fuel plates. Reactivity determinations were made for various thicknesses of solid steel in contact with one of each of these pairs taken singly (see Fig. 6).

Additional measurements were taken using laminated steel-water reflectors. The ⅛-inch water gaps between ½-inch plates of steel would serve as cooling channels for higher power reactors. These measurements yielded reactivities lower by about a factor of 2.5, compared to the solid steel data.

Bare and cadmium-covered indium foil traverses were taken through a number of solid and laminated-steel reflectors at varying distances from the core-reflector interface. Either solid or laminated reflectors completely eliminated flux peaking in the region. However, reflector separations from the core face of one-inch or more had little or no effect.

Future applications of such a reflector are presently being studied by design and analysis groups.

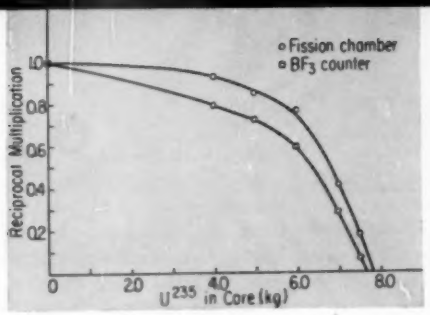


FIG. 2. Inverse multiplication, as function of fuel loading, predicts critical mass of 7.8 kg with all rods withdrawn. This corresponds to 17 elements (8.07 kg U^{235})

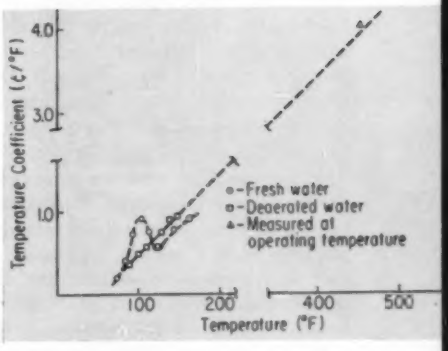


FIG. 3. Circled points show anomalous temperature coefficient from bubbles in fresh water. Deaerated water gave good agreement with subsequent measurement at high temperature

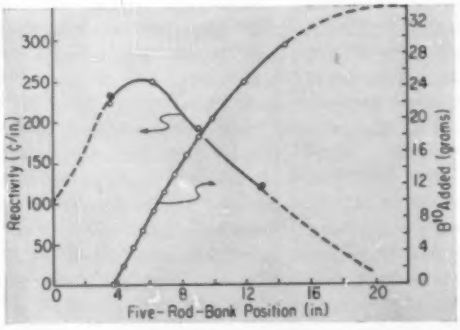
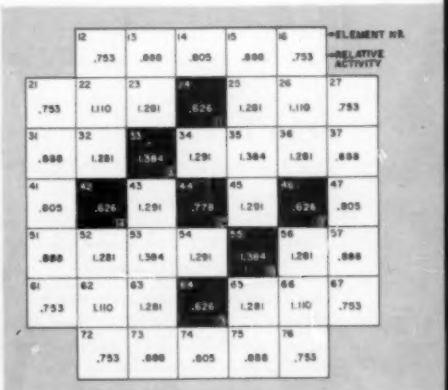


FIG. 4. Five-rod-bank reactivity calibration (left scale) and B^{10} compensation as function of bank position (distance withdrawn from core)

FIG. 5. Average activity per element determined by longitudinal bare-gold traverses through element centers and normalized to overall activity of unity. Black squares represent control-rod elements



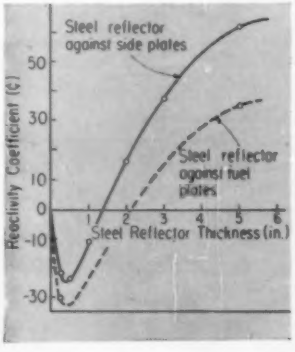


FIG. 6. Reactivity coefficients obtained for various thicknesses of stainless-steel reflector show promise of improved core performance with this reflector material

Continued from page 51

port for the fuel elements and bearing surfaces for the control rods, is mounted securely on the reactor-tank floor and the control-rod rack and pinion assemblies are aligned with respect to the lateral ports. (Overhead drives used during ZPE-2 studies are also shown in Fig. 1.)

Neutron-sensitive ion chambers and a motor-driven Po-Be source are fixed to the top of the reactor tank and located at the horizontal core midplane so that neutrons generated by the source pass through a minimum of water and a maximum of fuel prior to collection by the ion chambers. This arrangement produces adequate currents or counting rates (depending on the type of chamber) for control purposes at the console. All moderator and control-rod actions are directed remotely from the console located in a nearby control room.

Auxiliary experimental materials for ZPE-1 were minimal and included principally $0.50 \times 0.020 \times 23.0$-in. boron-steel strips containing 1.01% natural boron. These strips were hung, as required, uniformly between fuel plates and fastened to the core-support structure.

The steel reflectors used for ZPE-2 consisted of ten $0.5 \times 15.0 \times 24.0$-in. steel plates with a centered hole and fitted steel plugs for flux traverses. These plates could be bolted together to form either solid steel of various thicknesses or steel-water laminations. The assembled reflector was supported by the reactor tank floor and was located against a single core face.

Experimental Procedures

Since the ZPE-1 studies were conducted with the actual APPR-1 core-support structure, fuel elements and control rod drives, the problems peculiar to the experiment were essentially limited to those of acquiring the proper data with operating safety. The experimental observations may be grouped as either (a) reactivity measurements or (b) neutron-flux measurements.

Reactivity. The reactivity measurements involving small changes in reactivity on the order of \$0.10 (\$1.0 = 0.0073 units of ρ) can be made directly by relating the period associated with the change to reactivity via the in-hour equation. Measurements of much larger reactivities can only be made by compensating with previously calibrated control rods or alterations in the material content of the core. Determination of the available excess reactivity in the APPR-1 core, (which would ordinarily necessitate full withdrawal of all control rods) was accomplished by distributing boron–stainless-steel strips within the core. The temperature coefficients of reactivity, for example, were determined through the use of calibrated control rods.

Flux. Neutron-flux measurements can be made by activating small foils of various materials such as gold, indium, manganese, or enriched uranium-aluminum alloy or by use of more elaborate, pencil-thin fission chambers and other devices. Comparison of the activation studies by Oak Ridge National Laboratory during the APPR-1 critical-experiment program indicated that in regions of fairly constant neutron spectrum bare-gold activations represented power distributions satisfactorily. As a consequence, gold activations were used exclusively during ZPE-1 for gross radial and longitudinal flux measurements with occasional cadmium-covered-gold activations throughout the core, particularly in regions of rapidly changing spectrum. The 0.020 in. cadmium covers used were essentially black to thermal neutrons below ~0.5 ev and permitted a two-group comparison of the neutron spectrum, as seen by gold. Measurements with enriched uranium-aluminum alloy taken during ZPE-2 verified the further similarity between the neutron flux as seen by uranium and the gold thermal group (bare minus cadmium-covered gold) in regions of rapidly changing spectrum.

The gold foils were positioned within the core with the help of Scotch tape, rigid Plexiglass strips and thin cellophane. The foils were first wrapped in cellophane and then taped to the Plexiglass strips. These strips, roughly $0.5 \times 0.125 \times 26.0$ in., were slipped between the appropriate fuel plates. Other variations of this technique were used to obtain measurements in a few awkward corners and in the control-rod regions. The activated foils were counted in a modest scintillation-type counter, using relatively common techniques for normalization to previous activations and corrections for decay. Of course, many refinements, suitable to the occasion, were used to improve the procedures for both reactivity and flux measurements, the details of which are described with the reported data (*3*, *4*).

* * *

The capable direction of the APPR-1 core development by J. L. Meem and the efforts of the entire team are acknowledged. The APPR-1 critical experiments were creditably performed by Dixon Callihan, et al. A major portion of the ZPE-1 experimental work was performed by W. R. Johnson and S. D. MacKay.

ZPE-1 Time and Money

The distribution of operating time for the ZPE-1 series was:

Time reactor critical	**250 hours**
Time reactor approaching critical	**150 hours**
Time adjusting core parameters	**400 hours**
Number of startups	**195**

The average operating power level was about one watt.

Since the experiments used the actual APPR-1 core components, little money was needed for experimental materials; hence labor accounted for most of the program cost. The following breakdown has been adjusted to include the value of services contributed by four military personnel:

Direct labor—20 man-months	**\$13,000**
Overhead charges—250%	**32,500**
Materials	**1,000**
TOTAL	**\$46,500**

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Magnetic Tape Simplifies Handling of Nuclear Data

Savings of money, manpower and time at expensive research installations often justify the capital costs of convenient, versatile magnetic-tape methods

By D. W. HALFHILL, *Ampex Corporation, Redwood City, California*

MAGNETIC-TAPE techniques can be used to multiply the effectiveness of nuclear instrumentation by adding data-logging, -reducing and -analyzing capability. Advanced automatic data-handling processes, particularly computers, can be used for making investigations that have not been possible because of cost and time requirements.

Elsewhere in the nuclear field, magnetic tapes can be used in reactor monitoring and in collecting data from counting experiments. They are useful for multipoint data, stand-by recording and analysis of pulse sequences. A variety of methods is available. (See box on pages 56 and 57.)

Multipoint Data

Reactor instrumentation usually includes a large number of detectors measuring temperatures and neutron fluxes (*1*). Usually these quantities do not change rapidly, and scanning and sampling methods already developed for use in other fields are directly applicable. At the present time data are usually recorded on multipoint strip-chart recorders. The large mass of data to be handled imposes a severe data-reduction problem. Magnetic-tape recording can be used effectively.

PDM recording. Up to 900 separate measurements per second can be made with existing pulse-duration modulation (PDM) multiplexing equipment. Thus 30 detectors can be scanned 30 times a second, 45 detectors 20 times a second, or 90 detectors 10 times a second. Modified versions of the standard units can handle sampling rates considerably greater. It is also possible to use modified circuits for much smaller sampling rates.

A system to record sampled information is shown in Fig. 1. Detector signals are scanned sequentially to produce a pulse train that is recorded on a single track of the tape. More than one track can be used; as many as seven can be recorded on a ½-in. tape.

Some of these tracks can also be devoted to types of recording other than PDM. For instance, it is not uncommon to find direct, f-m, and PDM data recorded simultaneously on different tracks of the same tape. Through modular combinations, arrangements can be assembled to fit almost any desired recording situation. Over-all accuracy of PDM recording and playback is ~1%.

Digital recording. When it is convenient to digitize the data before recording, accuracy is limited only by that of the original data. The real

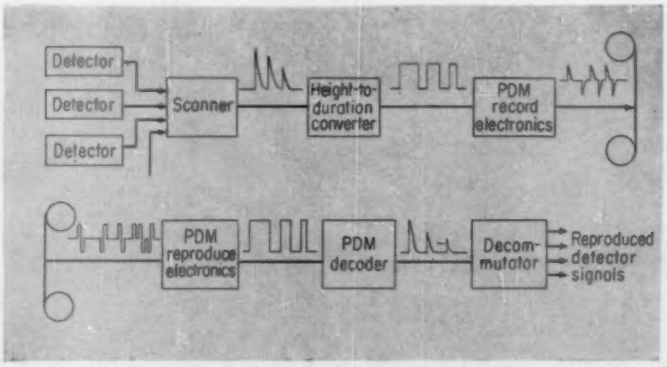


FIG. 1. Pulse-duration modulation (PDM) uses existing equipment to scan up to 900 measurements per sec. Pulse heights become pulse durations

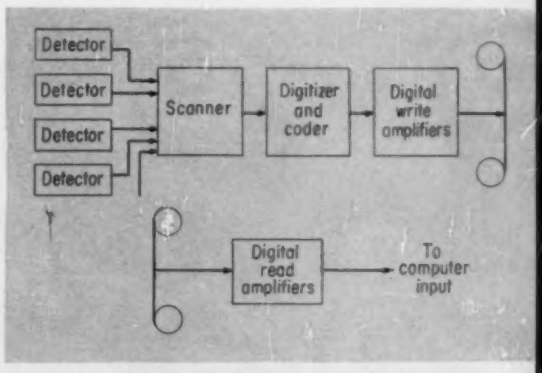
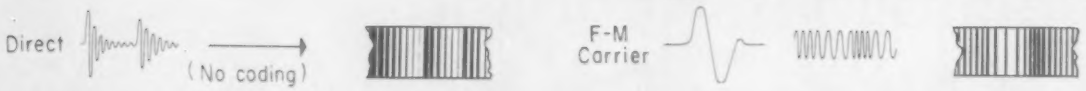


FIG. 2. In digital recording, analog information is converted to numerical form before writing

Magnetic-Tape Recording



Magnetic tape is a primary information-storage medium that offers unique services to the nuclear industry (*4*, *5*). It is particularly appropriate for the following purposes:

- To record data for which other media do not have necessary frequency response or data-handling capacity
- To speed up or slow down information transfer
- To log large volumes of data in short times
- To record data that must be recreated in "live" form
- To store information that must be available for immediate playback or erased, modified or updated

Significant elements of the system are:

1. The tape transport—it moves the tape at required speed across the heads and consists of a capstan to drive the tape, supply- and take-up-reel turntables, tape guides, etc.

2. Magnetic heads—they record and reproduce information by changing the magnetic flux in the tape.

3. The magnetic tape—it has an acetate or Mylar backing and a ferrous-oxide coating with special magnetic properties.

4. Auxiliary devices—they perform such functions as starting, stopping, end-of-reel sensing, detection of broken tape, reel brakes, etc. Widely divergent requirements exist.

5. Electronic circuits—they drive the magnetic heads and amplify the head signals.

Types of Recording

Magnetic-tape recording started with audio reproduction, and audio techniques have been extended to data recording. A number of specialized techniques have been adopted to give greater accuracy than the direct analog approach. The figure above illustrates the most common types of recording in use today.

Direct recording. Some data are recorded directly in varying flux levels on the tape. Optimum recording depends on proper choice of bias frequency and amplitude. (Bias, a continuous high-frequency signal, occupies the nonlinear portion of the magnetization curve of the tape. The desired signal is added to the bias on the linear portion of the curve. The bias frequency is so high that it is not reproduced on playback.) Direct recording provides maximum bandwidth, but it is subject to amplitude variations due to changes in head-to-tape contact and imperfections in the magnetic tape.

Increased amplitude accuracy is obtained by coding information in terms of either frequency or pulse duration. Amplitude variations are ignored by such systems. These techniques form the foundation of almost all instrumentation recording as used today.

However, direct recording can be used for useful information in pulse form if known statistical errors can be accepted.

Frequency modulation. As in f-m broadcasting, a frequency-modulated carrier eliminates distortion of the recorded data due to variations in signal amplitude. The principal source of signal distortion is tape-transport speed variation (flutter and wow) during either recording or playback. Where extreme accuracy is required, the tape transport is servo-driven on playback to minimize these effects (*6*).

Multiple data channels are combined on a single f-m track on a frequency-sharing basis. Standard commercial equip-

advantage in using tape-recorded digital information lies in the ability to feed it directly into a computer for processing (*1*). Figure 2 shows how this is done. After scanning, analog information is converted to numerical form by an analog-to-digital converter and coded before writing on the tape.

Data can be read by electronic circuits directly into the computer storage, eliminating additional processing during the computing operation. In experimental reactors this procedure probably will not be attractive for some time because of the initial investment required. On the other hand operation of commercial power reactors may force adoption of computer processing because the cost of routine manual handling and analyzing is prohibitive.

Stand-by recording. Another application involves stand-by recording for emergency conditions (*1*). A record of plant measurements before, dur-

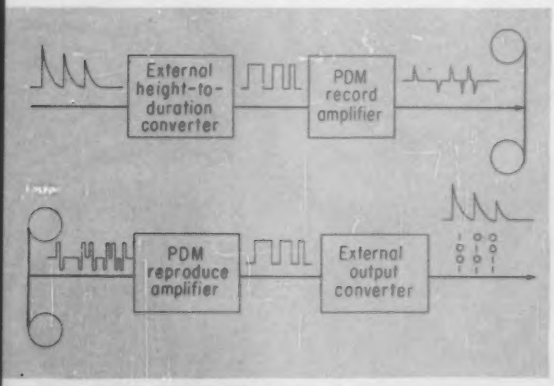


FIG. 3. Modified pulse-duration techniques are appropriate for small pulse rates. Output converter is duration to height or duration to digital

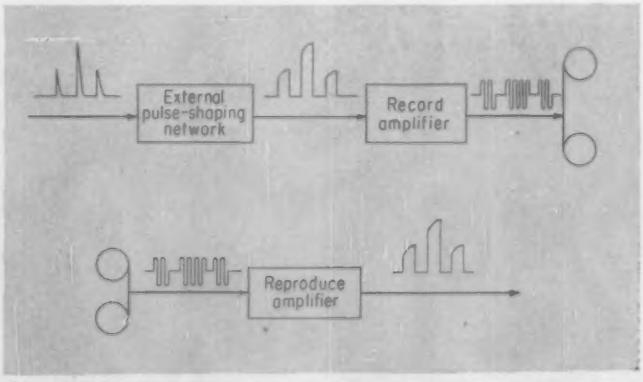
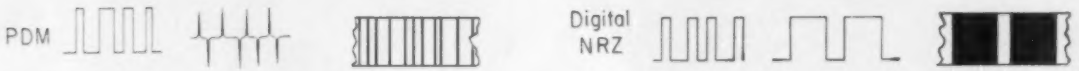


FIG. 4. F-M methods are used for larger pulsing rates and shorter recording times. Tape speeds are available from 1⅞ to 60 in./sec. Corresponding minimum pulse intervals are 8,000 and 250 μsec, respectively

—What Is It?



ment is used to multiplex signals in accordance with Research-and-Development-Board (RDB) standards set up for airborne telemetry systems (7).

F-M recording has the advantage of higher accuracy and linearity than direct recording. It permits recording of signal frequencies down to d-c. For good accuracy the upper limit of signal frequencies is ~15% of carrier frequency.

Pulse-duration modulation. PDM recording is used for periodically sampled pulses. Pulses of varying amplitude are converted to constant-amplitude pulses of varying width. The "record" amplifier differentiates PDM pulses so that only leading and trailing edges are recorded. On playback the pulse information triggers flip-flop circuits to reconstitute the PDM pulses. Decoding equipment outside the recorder interprets the PDM data in terms of digital information or analog-signal amplitude.

PDM systems provide the advantages of accuracy approaching 1% for the complete data system, relative independence from tape-speed variation, and the ability to handle time-multiplexed data. Maximum frequency response is limited to 10–20% of the pulse-sampling rate.

Digital recording. Information is sometimes available in binary-number form (for example, at some stages of modern pulse-height analyzers). Binary bits can be recorded on parallel tracks across the tape, or serially along the length of one track. Binary numbers have accuracy dependent only on the number of bits. Manipulations can be made almost without error. Also, digital information can be handled directly in a variety of logging, sorting, and computing operations with presently available digital handling equipment.

Practical accuracies in analog systems are ~1%. Some analog measuring techniques are not even this good. Analog-to-digital conversion equipment is available that presents information to the magnetic recorder in digital form suitable for input to a computer. Such a process reduces data handling, increases accuracy, and makes possible investigations that would otherwise require exorbitant expenditures.

Digital numbers are sometimes difficult to interpret as to performance and trends. Thus it is frequently necessary to reduce the data automatically to recognizable forms such as:

- Corrected and scaled tabulations automatically typed on log sheets and ready for analysis
- Low-frequency information corrected, linearized and plotted on strip-chart recorders. Higher-frequency data can be reproduced on photographic oscillographs
- X-Y plots automatically made directly from stored digital information
- Visual presentations made on oscilloscopes from the stored data.

A large investment is necessary to provide instrumentation systems with analog-to-digital converters and readout devices, but the investment is offset by the many advantages to be gained. The human element is virtually eliminated, reducing the incidence of error. The time elapsed between data taking and final results is considerably reduced. The actual expense of taking, handling, reducing and analyzing data is considerably reduced.

ing and after scram operation permits analysis of failure. Important information is recorded continuously on the tape loop and erased a few seconds or minutes later. If a scram occurs, the tape loop can be stopped to keep its record intact, or the information can be transferred automatically to a reel-to-reel recorder for a permanent record.

Taped reactor programs. Another reactor use for magnetic tape is in storing programs. For example, in an emergency shutdown of a reactor, a prerecorded emergency program accomplishes the required functions and provides assurance that all operations will be performed in the right order and on time. In training of operating personnel emergency situations can be simulated with a stored program. Prerecorded signal tapes can provide calibrating signals for reactor instruments.

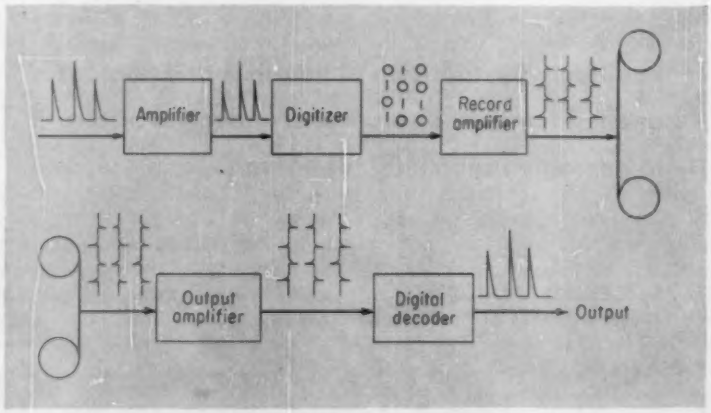


FIG. 5. Conversion of pulse-height information to digital form enables handling it with accuracy that is limited only by original information

Pulse Data

By ordinary means, pulse information must be analyzed in real time and during the process being studied. In contrast, it is convenient to record pulse-height and time-of-flight data on magnetic tape for manipulation and analysis at a later time. Methods depend on the rate at which information must be handled and on the accuracy desired.

Both analyzers and large accelerators are expensive. It is not economical to tie them up for long, slow measurements. Magnetic recording permits compressing long programs and extending short transients to make maximum use of expensive equipment. Recordings can be rerun as often as necessary

Continued on page 66

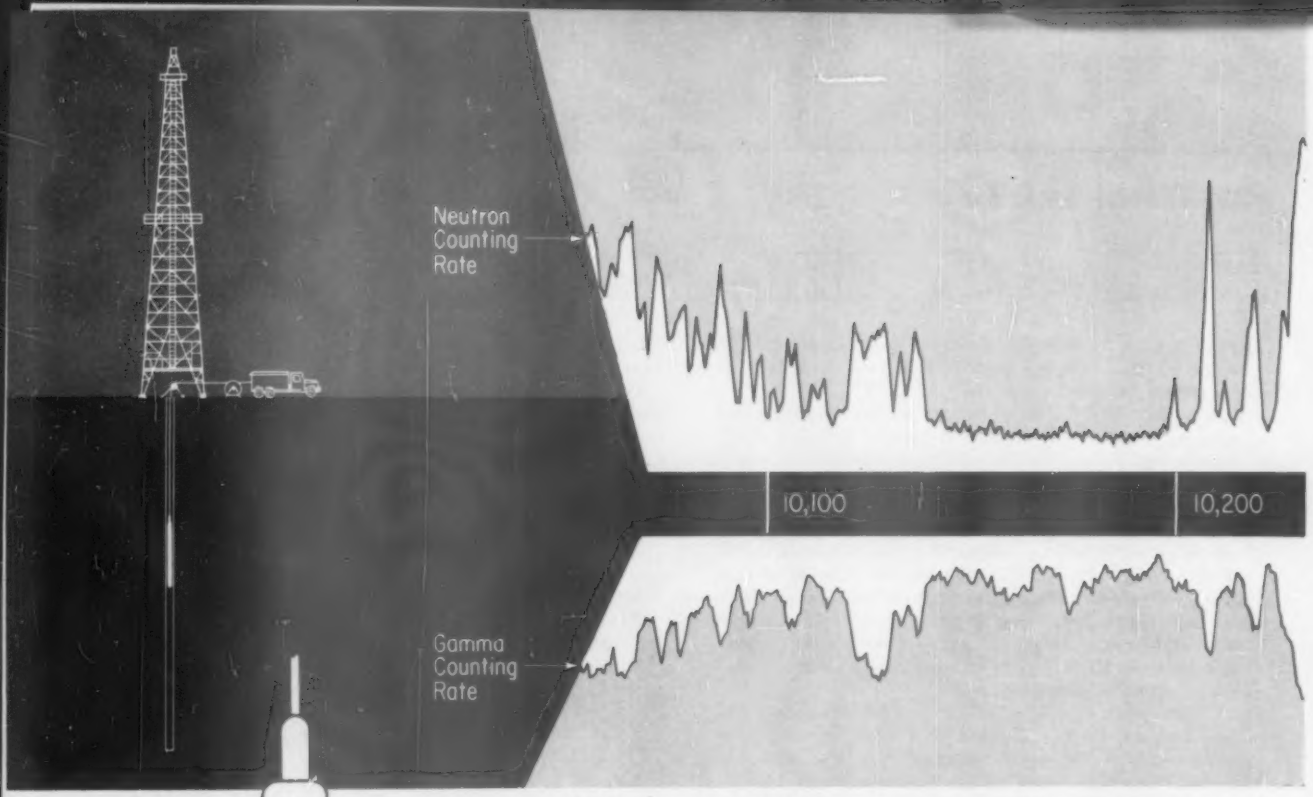


FIG. 1. Natural-gamma-ray logs and neutron-neutron logs are

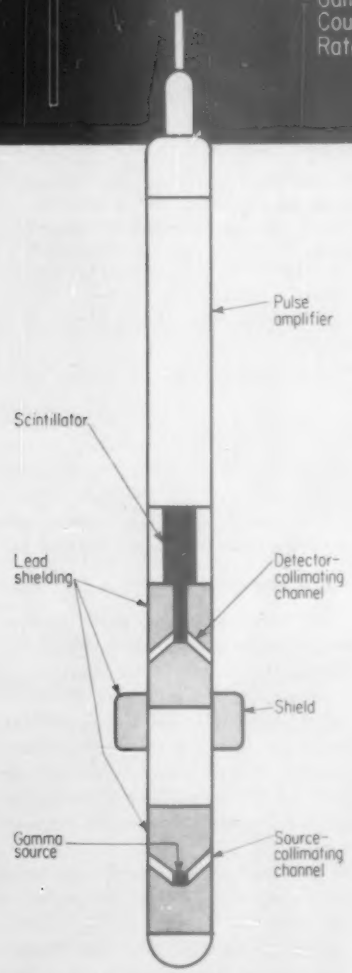
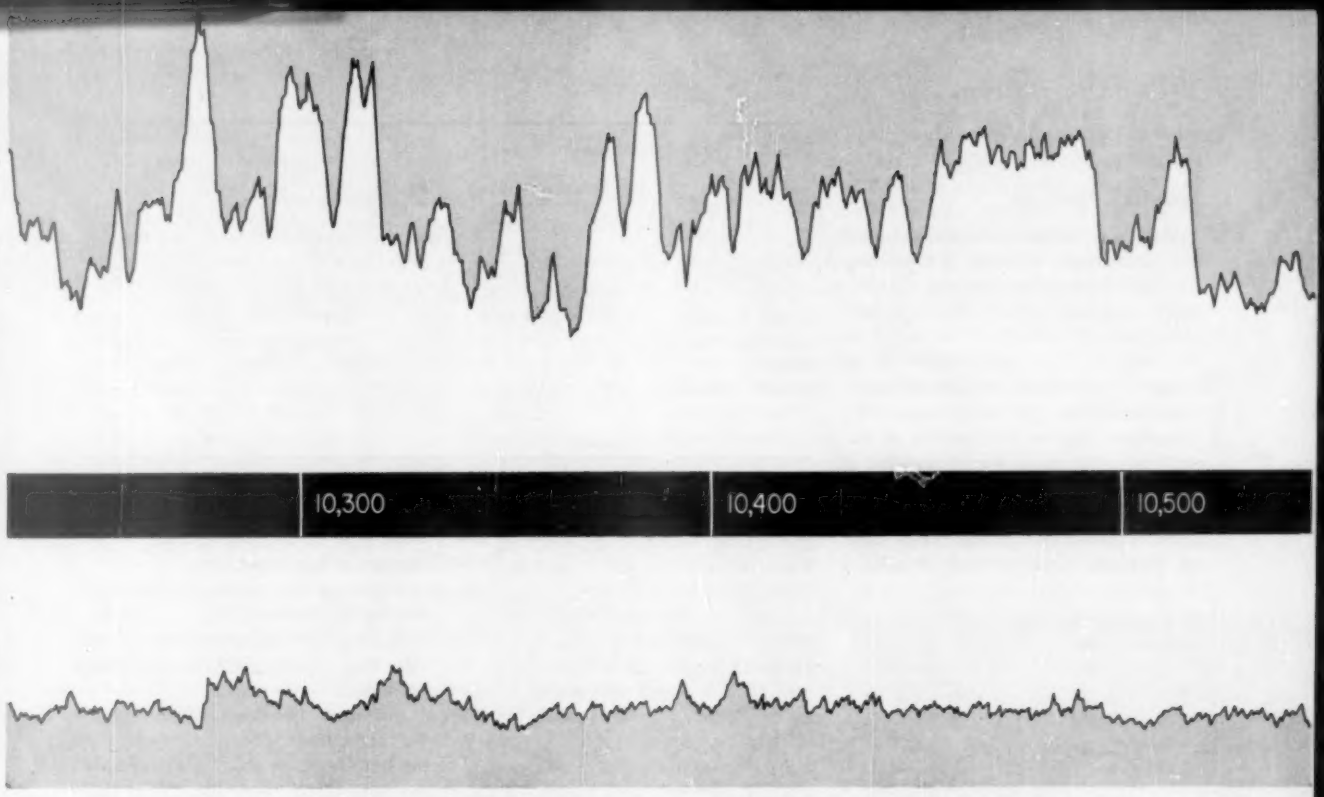


FIG. 2. Gamma-gamma tool has collimated source and collimated scintillation detector. Essentially it is an underground density gage

Using Nuclear Methods in Oil-Well Logging

Radioactivity, diffusion of neutrons and photons and n,gamma analysis reveal underground strata to geologists searching for oil

By RICHARD L. CALDWELL
Magnolia Petroleum Co., Dallas, Texas



often made in parallel. Calibration is done in especially prepared test wells or by comparison with core samples

WELL LOGGING is the geologist's method of studying the nature of subterranean rocks and soil. The most common log is the sample log obtained from rock cuttings brought up by the drilling fluid. To aid the sample log, instruments lowered into the borehole measure electrical, acoustical and nuclear properties. Interpretation of logs is based on comparison with cores taken in wells where logs have been run.

Nuclear logs are the only ones that work under almost any borehole conditions: in dry, open holes; in open holes filled with mud, salt water, oil, or gas; in cased holes dry or filled with fluid. Four types are in use and under development: natural-gamma-ray logs, scattered-gamma-ray or gamma-gamma logs, neutron-neutron logs, and neutron-gamma logs.

Nuclear logs have important limitations and are the subject of a continuous program of development. Recent improvements include new methods of calibration, theoretical treatments in simulated geometries, measurements in sample wells created for testing purposes and considerable field work.

NATURAL RADIOACTIVITY

Gamma-ray curves can be used alone as a qualitative log of rock formations. More frequently they are used with a neutron curve as shown in Fig. 1. Normally, high counting rates designate shales or volcanic ash. Low counting rates are found opposite anhydrite, salt, coal, limestone, dolomite or sandstone. However, some sand formations either are radioactive or contain radioactive waters and can be confused with shale. The gamma-ray log also is an excellent means of prospecting for economically valuable deposits of both uranium and potash (KCO_3).

An analysis of more than 500 sedimentary rock samples for total gamma-ray activity showed an increase in radioactivity directly proportional to an increase in shale, clay, silt and organic matter in the rocks (*1*).

Usefulness

The gamma-ray log can be interpreted to follow strata from one well to another, sometimes for hundreds of miles. These correlations are useful in mapping rock strata and defining productive intervals in wells that were cased before logs were obtained in them. Gamma-ray logs are also useful for depth-measurement control, especially when other logs and drill-pipe measurements do not agree.

Under some conditions, the amount of shale in a porous limestone or sandstone can be estimated from the relative photon counting rate. The shale content can be used to correct the neutron log in the evaluation of the porosities of shaly sands. In certain sandstone formations in restricted areas the gamma-ray log has been used to estimate the permeability of the formations to fluid transfer (*2*, *3*). Gamma-ray deflections opposite a shale bed and a shale-free portion of the sand are used, together with permeabilities from cores taken at these positions, to establish a calibration curve.

Calibration

Quantitative calibration is done in terms of specific sets of borehole conditions. These are used as standards, and corrections are given in the form of departure curves.

The American Petroleum Institute (API) is fostering establishment of primary-standard test wells for intercalibration of both gamma and neutron logs made by various companies. These artificial formations will contain known quantities of potassium, uranium-radium and thorium in amounts representative of average sedimentary formations (*4*). Similar standards for

neutron logs will have a wide range of porosities.

Spectral Analysis

With a scintillation-crystal detector and pulse-height analysis, it is possible to determine relative amounts of radioactive elements. With proper calibration absolute concentrations should be obtainable. This information is of interest in studies of sedimentary rock formations (*5*), in connection with theories of radioactive heating of the earth and for estimates of reserves of fissionable fuels.

Laboratory measurements. Quantitative measurements have been made of uranium, thorium and potassium content of several hundred sedimentary and igneous rocks (*4–7*). Gamma photons were counted in three energy intervals. The uranium values are <0.1–250 ppm, and thorium values <0.1–132 ppm. The average shale has about 13 ppm Th, 4 ppm U and 1.5% K, whereas the average limestone has 1 or 2 ppm Th and 2 ppm U. Among the carbonates thorium content decreases in the following order: dolomites, calcareous dolomites and calcite limestone. It is very difficult to estimate from the limited data available the average thorium and uranium contents of sandstone; the values for 19 clay-free sands are 1.7 ppm Th, 0.45 ppm U and 0.64% K (*8*). The thorium content of marine shales is higher than for nonmarine shales. Results for four kinds of shales are given in Table 1.

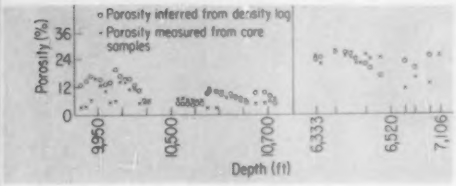


FIG. 3. Comparison of core-measured porosities and those from collimated gamma-gamma log shows log gives true values where borehole is not washed out

Field measurements. A number of three-component spectral gamma-ray logs have been run in boreholes (*4, 6, 9, 10*). By stopping the logging tool opposite the formation of interest gamma rays were resolved that are characteristic of the three radioactive species. Continuous logging with a channel for each radioelement was also performed at a speed of 1 ft/min (*9*). Spectral gamma-ray logging of 35 zones in five wells were made in intervals ranging in geologic age from Tertiary to Pennsylvanian; the lithology included shales, shaly sands and limestones (*10*). Variations in relative proportions of K, U and Th were noted among some of the sands, shales and limestones. Several thick shale sections were found remarkably uniform in their gamma-ray spectra. A more extensive study, together with geologic interpretations, shows results that agree remarkably well with laboratory measurements (*6*). The Th-U ratio closely reflects the lithology and to some extent reflects the variation in clay mineralogy of the more argillaceous intervals.

TABLE 1—Radioelements in Shales*

Sample	Concentration Th (ppm)	U (ppm)	K (%)
Potash bentonite	22.3 ± 2.1	4.1 ± 1.3	6.1 ± 0.3
Clay spur bentonite	39.9 ± 2.0	9.3 ± 1.3	0.7 ± 0.2
Illite	7.4 ± 1.9	17.4 ± 1.4	3.1 ± 0.3
Montmorillonite	30.6 ± 2.3	1.3 ± 1.4	0.9 ± 0.3

* From reference 4.

GAMMA-GAMMA LOGS

The scattering and absorption of gamma photons by light elements can be used to measure the density of the material in and around the borehole (*11*). Gamma-gamma logging has been used to locate the top of cement behind steel pipe, to measure the density of fluid in a producing well to tell where gas, oil and water are entering the well, to locate the interface of two liquids in an underground storage cavern and to measure the density of soils in civil engineering. A typical gamma-gamma tool is shown in Fig. 2.

Formation Density

Density information is of interest for the quantitative calculation of porosity, interpretation of gravity surveys, identification of seismic reflecting horizons and geological studies of shale density. A theoretical study of gamma-gamma logging was given in 1955 for a point source and a point detector along the axis of the borehole (*12*). The following results were obtained:

1. Scattered intensity decreases as rock density increases at ranges greater than 15 or 20 cm; the decrease is even sharper at longer ranges.

2. Intensity decreases exponentially as range increases.

3. In wells with large radii rock density has little effect on radiation intensity.

Methods. All practical logging tools for formation-density measurements use bowsprings to hold the tools against the side of the borehole. Logs have been made only in uncased holes. Density measurements in boreholes were described in 1954 for a tool that used a Co^{60} source and an ionization-chamber detector (*13*). Response of the instrument is affected by borehole size and borehole fluid density; so a caliper log of the well and the weight of the mud are necessary for interpretation. Porosity can be estimated from the measured density provided one knows the rock-grain densities.

Collimation. Exponential absorption can be better approximated by collimating the source and using a scintillation-crystal detector. In 1956 density-logging laboratory experiments of this type were mentioned (*14*), and

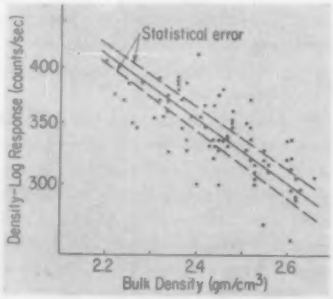


FIG. 4. Gamma-gamma logs give densities in agreement with core data even in materials where neutron logs fail to do so (16)

in 1957 field tests described (*15*).

Comparison between core-measured porosities and log-derived porosities is made in Fig. 3.

Energy discrimination. A similar tool with collimated source and scintillation-crystal detector detects gamma rays in a selected energy band (*16*). This is claimed to emphasize photons representing deepest penetration into the formation. In laboratory tests the log measured the density of artificial formations to an accuracy of ~2% regardless of hole size or formation chemistry. In field tests gamma-gamma logs give density and porosity results in acceptable agreement with core data, even in argillaceous zones where the neutron log does not show agreement (Fig. 4). In sections of the hole where washouts occur, the density log gave erroneous readings.

Another important advantage of density logs over neutron logs is that one density-log calibration curve should apply to all wells.

Cement Tops, Interfaces

One frequently has to locate the top of a cement liner of which there is no record. Radiation methods can be used to locate these tops. Similar methods locate hydrocarbon-brine interfaces.

Among possible approaches for cement-top location are scattered gamma photons, a modified neutron-neutron log and neutron activation of the aluminum, silicon or both in the cement. One gamma-gamma locator has no collimation of source and detector in polar angle (*15*). This tool has been used to locate ⅞-in. cement behind casing and ⅝-in. cement between liner and casing.

A similar tool has been used to locate the hydrocarbon-brine interface in underground salt-dome storage caverns. A pad of oil on top of the brine prevents solution of the salt where the access pipe is cemented in its casing shoe. Caverns in salt domes are used to store liquid petroleum gas (LPG). The LPG replaces diesel oil on top of the brine after the cavern is formed. Position of the hydrocarbon-brine interface should be known for protection of the casing shoe and maximum usefulness of available storage volume. It is readily located on the gamma-gamma log (*17, 18*). One 2-in.-dia tool contains a Co^{60} source and a sodium-iodide detector. In addition to the LPG-brine interface, the log also shows the location of the casing shoe and the collars used to join sections of tubing.

Fluid Density

In a producing well, density measurements of borehole fluid determine where gas, oil and water are entering the well. To be practical the tool must go through tubing that in some cases is only 2 in. in diameter. This limits the thickness of collimating material. A tool for borehole-fluid density measurements uses a Tm^{170} source of low-energy gamma photons to make collimation possible and provide appreciable attenuation of the gamma rays in passing through low-density fluids (*15*).

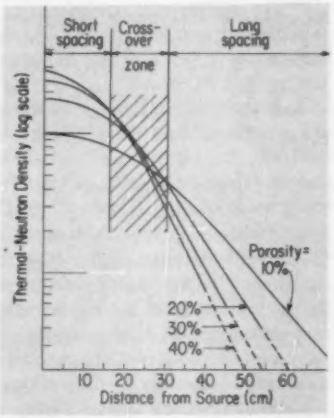


FIG. 5. Calculations of thermal-neutron density in porous silica show that, for proper source-detector spacing, response is determined by hydrogen content (23)

The borehole fluid is brought inside the tool, which contains a scintillation-crystal detector. For a 10-in. source-detector spacing—the maximum permissible without unduly limiting depth resolution—the change in counting rate in passing from oil to water is about 40%. This is 75% of the sensitivity calculated for narrow-beam collimation of source and detector. In going from water to air the change is ~400%.

Soil Density

Similar methods are used for soil-density determinations (*19, 20*). Tools have been developed for use either on the surface or in a small-diameter tube.

NEUTRON LOGS

A neutron log is made by lowering a source of fast neutrons and a detector of either neutrons or gamma photons (*21*). The source is usually Ra-Be or Po-Be with a neutron output of 5–20 × 10^6 n/sec. Systems that use neutrons from the *d-t* reaction are also in development. Figure 1 shows a neutron-gamma log alongside the corresponding natural-gamma-ray log.

Theory

A theoretical analysis of the neutron distribution in the vicinity of a well bore is useful as a basis for improved techniques and quantitative interpretations. Calculations have been made of thermal-neutron distributions due to a fast-neutron source in an infinite homogeneous medium with spherical symmetry (Table 2). An error in the thermal-neutron absorption cross section used for silicon results in a large overestimation of the thermal-neutron density in sand, particularly in dry sand (*22*). So far, calculations have not been made for the cylindrical geometry that would include the effect of a borehole and the fluid in it.

In slowing down, the typical neutron travels 11–55 cm, depending on the hydrogen content of the rock. The average diffusion length of thermal neutrons is only 2–5 cm in highly hydrogenous media, but it is considerably greater in dry rock. Thus in hydrogenous media the average neutron is captured within a few cm of the point where it becomes thermal. The total distance of travel (slowing-down and diffusion) is an inverse function of hydrogen content.

For the source-detector spacings commonly used, the neutron log indicates the slowing-down properties of an appreciable thickness of rock. The calculations show the presence of an inversion effect for both neutron-neutron and neutron-gamma logging, making it necessary to select the optimum spacing for the solution of specific geologic problems.

Experimental checks. Measurements of the spatial distribution of indium-resonance neutrons about a "point" Ra-Be source in pure $CaCO_3$ (limestone) and SiO_2 (sand) compare favorably with the predictions of age theory (*23*). The space integrals indicate about 10% more absorption in $CaCO_3$ than in SiO_2 during moderation. The results of this study were applied to logging with a discussion of the predictions possible within the limitations of this theory (*24*). Figure 5 shows

the thermal-neutron density for a point source of Ra-Be neutrons in an infinite formation of porous silica with water-filled pores. The source-detector spacing can be chosen so that the neutron-log response is determined chiefly by hydrogen content.

Although hydrogen is most important, other elements in the formation (oxygen, silicon, carbon, calcium, etc.) affect the detector response. Also, the thermal-neutron distribution can be perturbed by the presence of absorbing elements such as chlorine and iron.

The distributions of thermal and epithermal (indium-resonance) neutrons in continuous hydrogenous media and simulated formations have been measured (*25*). The distributions in barite drilling mud and oil were essentially the same as in water. Materials such as well fluids and cement located between the logging tool and the borehole wall impose serious limitations on sensitivity and accuracy. The intensity of epithermal neutrons was a more reliable indicator of hydrogen content than the thermal-neutron response. The neutron-neutron method of chlorine determination was not sensitive enough to be useful with reservoir brines.

Applications

So far the principal applications of neutron logging are to porosity measurements, gas-fluid determination, and soil-moisture measurements.

Porosity. In reservoirs free of clay, shale or other hydrogen-containing matrices, the log response is a measure of porosity. Porosity is proportional to hydrogen content since hydrogenous fluid fills the pores. Calibration can also be based on results in test wells constructed of rock of known porosity.

TABLE 2—Thermal-Neutron Parameters*

Material	*Slowing-down length (cm)*	*Thermal-diffusion length (cm)*	*Diffusion constant (10^4 cm²/sec)*
Anhydrite	23	8.7	22
Oil	9.3	2.1	2.2
Limestone	29	15	21.5
Gypsum	11	3.5	4.6
Damp sand (22% water by volume)	17	10	9.4
Wet sand (45% water by volume)	11	5.1	4.3
Dry sand	55	160	49

* From reference 12.

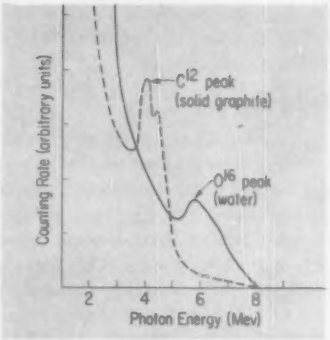


FIG. 6. Prompt gammas from 14-Mev-neutron activation permit identification of carbon and oxygen in underground formations

A number of borehole factors also influence the measurement. Standard curves showing the effects of these various factors are used to make suitable corrections. Each logging service company supplies a set of standard calibration curves to users of its equipment and services. Each logging tool is calibrated in a hydrogenous cylinder before and after a survey. On a semi-logarithmic plot the curve of neutron-log deflection (linear scale) versus porosity (logarithmic scale) is approximately linear. Neutron deflection decreases when the porosity (hydrogen content) increases because increased hydrogen means more effective moderation and neutron capture nearer the source.

For a given formation, neutron response depends on the type of fluid filling the pores, the amount of hydrogen contained in the matrix (mostly found as water bound in shales), temperature and pressure (especially if gas is the fluid), and porosity. In a clean sand, the hydrogen content gives porosity directly. For this reason the neutron log has been used in many thousands of wells to give a quantitative measure of porosity. The porosity resolution is greater at low porosities; so the neutron log has been particularly useful in carbonate reservoirs where porosities are often considerably lower than in many sandstone formations. In shaly sands or shaly carbonate rocks the porosity measurements may be questionable or in serious error.

Gas-fluid identification. Under favorable conditions the neutron log can also be used to distinguish between gas and liquid. From chemical analysis reservoir fluids can be classified in order of increasing hydrogen concentration as follows: dry gas, wet gas, condensate gas, oil, water, dead heavy oil. Of these only gas can be recognized on the log. Gas produces a much higher neutron deflection than liquid-bearing sands if the depth of invasion of the borehole fluids into the formation is small. At great depths where pressure and temperature are high, the contrast between gas sands and water or oil sands is less conspicuous.

In some fields where gas is not evident on the conventional neutron log, a second neutron log is run with a greater spacing between source and detector (*26*). The first log responds primarily to that depth of gas sand invaded by borehole fluid. The response with larger spacing is more influenced by the virgin-gas zone. If there are no large variations of porosity and shaliness, gas sands show a departure between the two curves. Under unfavorable conditions no visual interpretation is possible, but the gas sands can be picked graphically if enough known oil and water sands of different porosities are present.

Another technique to delineate gas zones is to make a flowing log while the well is producing fluid. This method has been used successfully in wells which, after some period of operation as an oil producer, have gone to producing gas or a high gas-oil ratio (*27*).

Soil moisture content. The neutron-logging method is also used for soil moisture content in civil engineering and agricultural work (*28, 29*).

Neutron-Gamma Logs

Laboratory measurements have been made of the intensity of neutron-capture gamma rays in simulated drill holes of various types (cased and uncased, empty and water-filled) with sand formations dry, dampened and saturated with fresh water and brine (*11*). In a 6-in.-dia well, the gamma intensity increases with hydrogen content for source-detector separations smaller than ~16 in. and decreases for greater separations. At a fixed source-detector spacing gamma intensity can be used to estimate hydrogen content. The slope of the curve of counting rate as a function of spacing changes with hydrogen content. Hence the use of

two gamma detectors at fixed distances from the source should be a better means of quantitative porosity measurements.

Drilling mud and other strongly hydrogenous well fluids impair the usefulness of the neutron-gamma measurements unless the liquid layer separating the probe from the formation is very thin and its thickness accurately known. In experiments comparing fresh water and brine saturation of sand no significant difference was observed between the two fluids, although one might expect to detect brine by gamma rays from thermal-neutron capture in chlorine.

Prompt-Gamma Spectra

Within the past three years there have been a number of papers on the energies of prompt gamma rays from bombardment of earth materials with 14-Mev *d-t* neutrons and Po-Be neutrons.

14-Mev neutrons. With a low-energy accelerator (250–500 kev) the

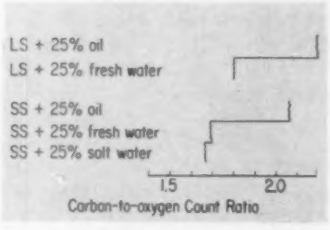


FIG. 7. Ratio of counts at peaks of Fig. 6 is an indication of carbon-to-oxygen ratio. Figure shows this can be used to distinguish between water and oil saturation of rock formations. (LS indicates limestone; SS means sandstone)

d-t reaction gives neutrons at yields more than two hundred times that of a conventional radioactive logging source. Inelastic scattering of 14-Mev neutrons by common earth elements produces energetic gamma rays that are readily resolved with a scintillation spectrometer.

The prompt gamma photons from neutron bombardment of all the common earth elements found in sedimentary rocks have been studied (*15*). Gamma rays of energy 0.1–10 Mev were measured. In geometrical arrangements approximating those found in a borehole most of the elements of interest to the petroleum geologist were identified. Typical results are given in Fig. 6. Table 3 is a list of useful prompt gammas. Identification of hydrogen, carbon and oxygen is of obvious interest for distinguishing oil or gas from water. Magnesium and calcium analyses are of interest in the development of certain oil reservoirs found in carbonate rocks where secondary dolomitization is responsible for porosity and permeability.

In many reservoirs, such as the Edwards formation in Central Texas, prediction of porosity can be made from the chemical composition of carbonate rocks. Silicon analysis by fast neutron bombardment combined with aluminum analysis by slow-neutron activation is sometimes useful for distinguishing clean and shaly sands. Oil in shaly sands is difficult to locate by conventional logging methods because of the similar electrical conductivity of shale and salt water.

To further evaluate these logging possibilities, neutron irradiation was made of common sedimentary rocks and of rocks plus fluid to simulate oil and water saturation. The ratio of the gamma counts at carbon and oxygen energies was shown to be useful in distinguishing oil and water. A log using this method is shown in Fig. 7. For evaluation of magnesium logging Edwards dolomite and limestone were used to obtain the results given in Fig. 8. The magnesium gamma ray at 1.37 Mev is prominent in dolomite and absent in limestone. Sand and shale both show a prominent 1.78-Mev gamma due to Si^{28}.

The data on light elements also indicate that gamma rays from 14-Mev neutron bombardment of sedimentary materials should be useful in logging to identify coal and sulfur deposits (*15*). Several service companies are developing borehole accelerators and *d-t* discharge tubes as sources of 14-Mev neutrons for well logging (*30*).

Po-Be, Ra-Be neutrons. The conventional neutron-gamma log is unable to differentiate directly between water-bearing and oil-bearing strata. Since in many wells the water is highly mineralized, especially with sodium chloride, it is possible to identify water by the hard gamma photons from thermal-neutron capture in chlorine.

Two Russian papers show identification of oil-bearing and water-bearing formations by spectral analysis of the gamma rays of the neutron-gamma log-

TABLE 3—Prompt γ-Rays from Neutron Irradiation

Material irradiated	*Photon energies (Mev)*	*Isotope producing photons*
Magnesium	1.37	Mg^{24}
Silicon	1.78	Si^{28}
Hydrogen (water)	2.2	H^{1}
Hydrogen (oil)	2.2	H^{1}
Sulfur	2.25	S^{32}
Calcium	3.73	Ca^{40}
Carbon	4.4	C^{12}
Carbon (oil)	4.4	C^{12}
Oxygen (water)	6.7	O^{16}

ging method (*31*, *32*). The sodium-chloride content of the water was high—10–15% by weight. The counting rate opposite the salt water was 15% higher than that opposite the oil.

In Britain prompt gammas from neutron capture were studied with an artificial borehole 20 ft long and 3 ft in diameter (*33*). The counting rate in the brine stratum exceeded that in the oil stratum by about 10% over a range of gamma energies of ~5–7 Mev (Fig. 9).

In 1957 several American papers gave results of spectral analysis of gamma radiation from neutron bombardment of various materials in a barrel geometry designed to simulate borehole conditions. From bombardment of kerosene, fresh water, brine, sulfur and limestone-sulfur mixtures, gamma-ray peaks from hydrogen, calcium, sulfur and chlorine were identified with relative ease (*34*). No fluid was used in the borehole. Both sulfur and chlorine could be determined quantitatively.

Neutron-capture gamma spectra for artificial formations of crushed rock material saturated with fresh or salt water were obtained in a fluid-filled borehole (*35*). Spectra were obtained for formations of sand and fresh water, sand and salt water, limestone and fresh water, dolomite and fresh water, and synthetic gypsum or anhydrite and fresh water. Spectral peaks were obtained for the neutron-capture gamma rays of hydrogen, silicon, chlorine, calcium, magnesium and sulfur. The various formations could be identified by their gamma-ray spectra. Spectra taken in different hole sizes showed that the effect of drilling fluid is similar to that of water and that spectra can be taken in holes as large as 10 in. in

diameter. Comparison of the sand–fresh-water and sand–salt-water curves indicates that the spectra above 5 Mev can be used to identify salt water. For salt water of salinity 40,000 ppm the counting rate at 5.1 Mev was double that of fresh water.

Similar results were obtained with real saturation of large outcrop samples of sandstone as well as with simulated saturation (*15*). Oil and salt water were identified on the basis of the ratio of counting rates at 4.4 Mev and 6 Mev in the differential-pulse-height distributions. The carbon/oxygen-chlorine ratio as a measure of the kind of fluid in a rock can best be used in a fluid-free uncased hole. Integral bias for energies greater than 6 Mev gave a 50% change in counting rate between simulated salt-water and oil saturations for a 25% porosity sandstone and an uncased, fluid-free hole. With casing and borehole fluid the difference in counting rate was greatly reduced.

Delayed Gammas

The chemical composition of rocks can be investigated by measurement of the half-lives and energies of delayed neutron-activation gamma rays. Fast-neutron bombardment produces different radionuclides from those formed by thermal neutrons.

With fast neutrons. Bombardment with 14-Mev neutrons can, in principle, be used for analysis of many elements of interest in petroleum geology. Table 4 gives computed values for the relative sensitivity of the fast-neutron activation method for analysis of common sedimentary elements (*36*). More than 500 geologic samples have been analyzed quantitatively for silicon [$Si^{28}(n,p)Al^{28}$] and aluminum [$Al^{27}(n,\alpha)Na^{24}$] with considerable savings in time and effort over wet chemical means. The method is accurate to within 5% for samples containing 0.4 gm or more of silicon dioxide and 0.5 gm or more of aluminum oxide.

Experiments on oxygen activation [$O^{16}(n,p)N^{16}$] were performed with a geometry that approximated borehole conditions (*15*). When the fluid was 25% of the rock-plus-fluid volume, the change in counting rate in going from water to oil saturation was about 29%.

Field evaluation of aluminum, silicon and oxygen logging based on delayed gamma rays from 14-Mev neutron bombardment is dependent on the use of a borehole accelerator. Some preliminary field experiments of these logging methods have been performed but no results have been published (*37*).

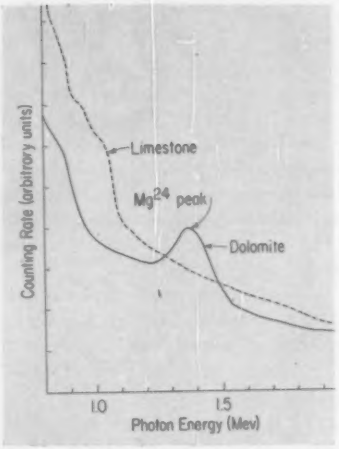


FIG. 8. Mg^{24} peak in prompt-gamma spectrum excited by 14-Mev neutrons differentiates between limestone and dolomite

With slow neutrons. Russian researchers have reported laboratory and field results of induced-radioactivity methods to locate oil–salt-water contacts and deposits of bauxite, copper manganese and other minerals (*38*). The most comprehensive reports have been on the activated-sodium method of locating oil-bearing and water-bearing strata (*39*). When synthetic salt-water-bearing and oil-bearing sandstone beds were irradiated with neutrons from a Po-Be source (moderated by the borehole fluid) the induced 15-hr Na^{24} activity of the water-bearing bed was three to four times as high as that of the oil-bearing bed within 20–30 hr after the end of irradiation.

The biggest effect was observed by concentrating on high-energy gamma rays to reduce induced background activity from manganese and calcium. Field tests were made in a sandstone of ~20% porosity. The sodium content totaled 0.01 gm/cm³ of the water-bearing sandstone. The well was cased and cemented. The irradiation time was 5 hr and measurements were made 10–15 hr after the end of bombardment. The induced activity opposite the water-bearing part of the bed was approximately six times as great as that facing the oil-bearing section.

Induced activity tests were also run in other oil fields with useful but less spectacular results (two-fold difference opposite water and oil portions of bed). This was tentatively attributed to salinity of the cement behind the casing. Tests of this method have also been made in a cased well (*40*). The gamma radiation 13 hr after irradiation was several times as great opposite the water-bearing bed as opposite the oil-bearing zone.

Na^{24} is produced not only in the $Na^{23}(n,\gamma)Na^{24}$ reaction but also in the $Mn^{55}(n,p)Na^{24}$ and the $Al^{27}(n,\alpha)Na^{24}$ reactions. The cross sections for the latter reactions, which involve fast neutrons, are smaller than the thermal-neutron-capture cross section of Na^{23}; 37-min Cl^{38} might also be used to distinguish between oil and salt water. However, the induced activity of

TABLE 4—Sensitivities of Activation Analysis*

Element	*Half-life*	*Isotope produced*	*Photon energy (Mev)*	*Relative activity†*
Oxygen	7.4 sec	N^{16}	6.1, 7.1	1.05×10^{-2}
Silicon	2.3 min	Al^{28}	1.8	1.31×10^{-3}
Phosphorus	2.3 min	Al^{28}	1.8	8.5×10^{-4}
Aluminum	9.5 min	Mg^{27}	0.84, 1.0	8.56×10^{-5}
Magnesium	1.0 min	Na^{25}	0.4, 0.6, 1.0	7.54×10^{-5}
Silicon	6.6 min	Al^{29}	1.3, 2.4	1.02×10^{-5}
Iron	2.6 hr	Mn^{56}	0.8, 1.8, 2.1, 3	4.58×10^{-6}
Magnesium	15.0 hr	Na^{24}	1.4, 2.8	3.02×10^{-6}
Silicon	9.5 min	Mg^{27}	0.84, 1.0	2.09×10^{-6}
Aluminum	15.0 hr	Na^{24}	1.4, 2.8	1.41×10^{-6}
Chlorine	32 min	Cl^{34}	1.1, 2.1	9.5×10^{-7}
Potassium	37 min	Cl^{38}	1.6, 2.1	6.15×10^{-7}
Potassium	1.8 hr	A^{41}	1.3	5.25×10^{-7}

* Computed for 14-Mev-neutron irradiation.
† For bombardment times short compared with the half-life of the activity.

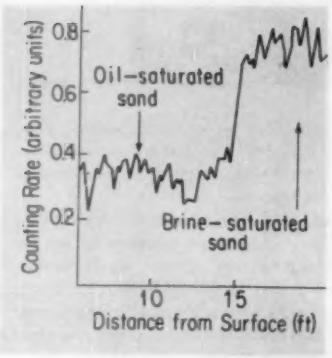


FIG. 9. Capture gammas in the 5–7-Mev range indicate interface between oil- and brine-saturated sand (33)

manganese (in the casing) and calcium was so high as to hamper analysis for chlorine (*39*, *40*).

Neutron bombardment of sandstone and shale can produce short-lived Al^{28} (2.3 min) by two reactions: (1) thermal-neutron capture in Al^{27} and (2) $Si^{28}(n,p)Al^{28}$ reaction of fast neutrons. Al^{28} activity has been produced in a shale by bombardment with a 10-c Po-Be source for 10 min (*9*). The borehole was water-filled. After the bombardment the scintillation counter was moved to a position opposite the bombarded zone and gamma rays of energy 1.8 Mev were counted. To identify clay and shale on the basis of aluminum content it is necessary to have a true thermal-neutron source. Even then there will be an Al^{28} background from clay in the drilling mud and filter cake and from cement outside the casing. In laboratory experiments it has been shown that neutron-activated aluminum can be used to differentiate between water-bearing and oil-bearing strata in a well (*40*). The radiation intensity of Al^{28} will be lower opposite water-bearing beds than opposite oil-bearing beds, provided the beds contain the same porosity and fraction of aluminum. The difference is due to the lower density of thermal neutrons in the water-bearing section, which usually contains chlorine. Chlorine has an abnormally large absorption cross section for slow neutrons (~33 barns).

* * *

The author wishes to express appreciation to C. I. Alexander and N. P. Stevens for helpful discussions on the manuscript and to the management of the Magnolia Petroleum Company for permission to submit this paper for publication.

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Magnetic Tape

Continued from page 57

to extract different kinds of information. Moreover magnetic tape allows the recording of vast quantities of data that could not be recorded and analyzed by any other means.

Statistics. Recently, investigators in England demonstrated the practicality of direct recording of nuclear-pulse data (*2, 3*). Suitably stretched pulses were recorded at a slow tape speed for a long time. Information played back for analysis at 200 times recording speed showed good correspondence with direct results.

For individual pulses, direct recording cannot be relied upon to produce accuracies better than ±10%. This is not good enough for instrumentation purposes. However, the random spread of accuracies around a point is ~3% at the half-amplitude level. In some nuclear measurements, detectors have a random spread of ~8% due to Compton scattering and other effects. Combining these two accuracies on a root-mean-square basis results in an over-all accuracy of 8.6%. Usable accuracy is degraded only 0.6%.

Methods. A variety of solutions are available for pulse-recording problems that require preservation of amplitude information:

A—Slow pulsing over several hours. For small pulse rates over a long period modified PDM recording techniques are suggested. The smallest tape speed consistent with the pulse durations is used. Conventional magnetic recorders operate at tape speeds of 1⅞–60 in./sec. Information is converted from pulse-height to pulse-duration form for recording as shown in Fig. 3. The output converter can be duration-to-height or duration-to-digital. Over-all accuracy is ~1% of full scale.

B—Fast pulsing for a few minutes. Frequency modulation is satisfactory for a moderately high pulse-incidence rate that must be recorded for a short time (Fig. 4). A 60-in./sec tape speed provides a bandpass of 0–20 kc for sinusoidal voltages.

A separate channel is used to record each function. For minimum requirements, a one- or two-channel tape recorder with ¼-in. tape can be used. A ½- or 1-in. tape makes additional parallel tracks possible. If additional recording time is required, a slower recording speed is used. Accuracies of 1% of full scale can be expected if the system is calibrated just before measurements are taken.

C—High-speed digital recording. Converting pulse heights to digital form allows recording with an accuracy of 0.1% or better. High-speed digital-conversion equipment will handle rates of 50,000 pps or greater.

In the system of Fig. 5 voltage levels of scintillation-counter pulses are amplified for processing by an electronic digitizer. The processed information is stored on tape. On playback, the data are often read out at a different speed. Electrical information is processed by a digital decoder to produce an output train of pulses essentially duplicating those recorded.

Digitizer and decoder are often combined in a single unit. In some cases decoding is unnecessary; analyzing equipment accepts data from the recorder in digital form.

With a bit spacing of 0.003 in. on the tape the dropout rate (loss of data due to tape imperfections) can be expected to be no greater than 1 in 10^7. This probably makes no detectable difference in the accuracy of the statistical data produced by the recorder. If a higher error rate can be tolerated, the bit spacing can be reduced by recording at a smaller tape speed.

D—Very high pulse rates. A wide-band instrumentation recorder—an adaptation of the television recorder now in wide use—offers additional capacity. Using f-m techniques, pulses recorded at rates up to 100 kc can be recorded with an accuracy of ±2%. Digital data can be handled up to the 50-kc limit of present digitizing equipment with ½% accuracy. One hour of recording time is provided by each tape reel at 15 in./sec.

Special measurements. Multichannel recording equipment permits study of coincidence phenomena and accumulation of statistical data. The activity of a short-lived isotope can be recorded for repetitive analysis—such as correlation of time-of-flight measurements with pulse heights—over a wide range of values. Magnetic-recording equipment can be changed quickly and simply to perform different functions. Modular construction lends itself to rapid changes with its plug-in modular amplifiers and appropriate external encoders and decoders.

Magnetic Tape at Work

Two novel applications of magnetic-tape recording in the nuclear field are under development.

Ampex and General Atomic are cooperating on a development program for a portable magnetic recorder to preserve pulse-height information from long experiments at low counting rates. This development is based on work by Cavanaugh and Boyce (*2*).

The system will use direct amplitude recording and will affect the normal resolution obtained only slightly. The tape is speeded up on the playback to conserve pulse-height-analysis time. Preliminary work has shown that a marked improvement in information capacity can be had with more than one tape channel on a time-sharing basis.

Ampex and Panellit have designed a transient recording system that will record temperature, pressure and rod-position information for a nuclear reactor. Dynamic information from zero to 100 cps to 1% accuracy will be recorded by f-m techniques. A continuous time code will also be recorded to facilitate automatic data reduction including automatic digitizing of the information at fixed intervals. Information will be analyzed and correlated by means of a digital computer.

Accuracy is improved by automatic standardization of all a-c input levels. The time-code information is recorded in a digital form to the nearest second on a 24-hr basis.

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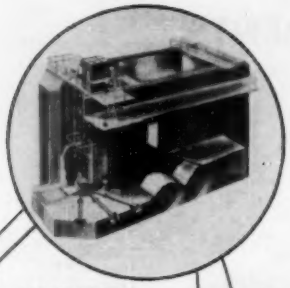
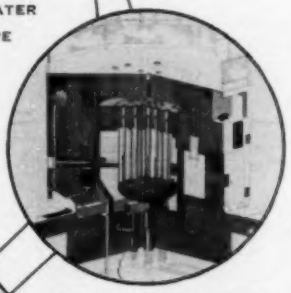
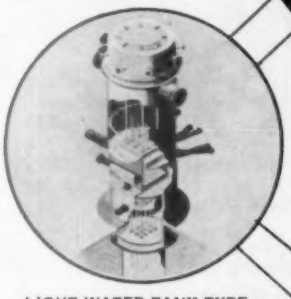


LIGHT WATER
POOL TYPE



HEAVY WATER TANK TYPE



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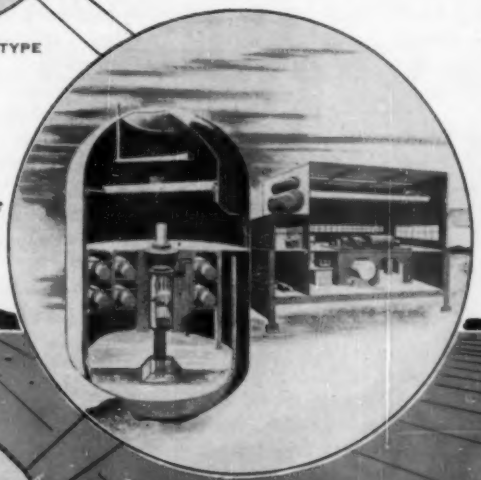
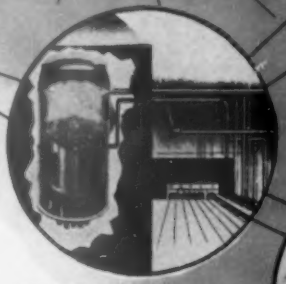


BOILING WATER POWER REACTOR



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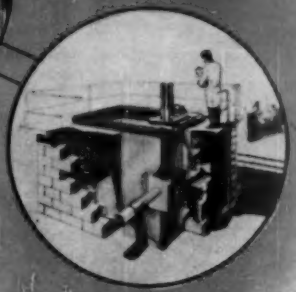

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Measuring γ-Ray Spectra with Large Plastic Scintillators

By G. L. BROWNELL, W. H. ELLETT
Physics Research Laboratory
Massachusetts General Hospital
Boston, Massachusetts

and H. D. LeVINE
Health and Safety Laboratory
New York Operations Office
U. S. Atomic Energy Commission
New York, New York

Large blocks of plastic scintillator should have many applications in medical and industrial fields requiring high sensitivity without precise spectral determinations. Though the spectral resolution is definitely inferior to that of NaI (see table), the plastic blocks still provide a valuable means of separating the spectra of known isotopes, such as in double-tracer experiments.

The Los Alamos "human counter," which uses a liquid scintillator, can separate the activities due to K^{40} (E = 1.4 Mev) and Cs^{137} (E = 0.66 Mev) but cannot determine the identity of an unknown isotope (*1*).

Recently Bird and Burch (*2*) published spectra of various isotopes obtained with large liquid and plastic scintillators. These spectra represent the differential energy distribution of the Compton interactions and have rather well defined peaks at the Compton edges. The peaks are not as well resolved as the total absorption peaks seen with NaI crystals for at least two reasons: the distribution covers a finite energy interval rather than having a discrete energy, and the poorer quantum efficiency and light transmission of plastic scintillators.

Light transmission is of particular importance for large scintillators since the path length of the light is appreciable. This condition is aggravated if the area of the light-collecting photocathode is small compared with the area of the scintillator. In this case, multiple reflections will be required to collect the light, increasing the path length greatly (*3, 4*).

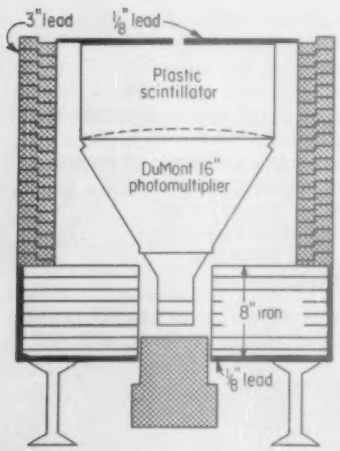

FIG. 1. Shielding of photomultiplier and plastic scintillator. Radiation sources were placed over 1-in. hole in lead sheet

Present Studies

We have investigated the Compton spectra produced in a 16-in.-diameter by 8-in.-long cylindrical plastic scintillator* coupled to a 16-in. Du Mont photomultiplier for maximum light collection. The scintillator was coated with a suspension of aluminum oxide in silica gel to improve its light-retention properties. Some difficulty was encountered in obtaining spectra with this system when unshielded because of its great sensitivity to scattered γ-rays. The addition of the scattered quanta had the effect of masking the decrease in counts per energy interval on the low-energy side of the Compton edge. Spectra were obtained by shielding the scintillator and photomultiplier (Fig.1).

The spectra obtained with this equipment are shown in Fig. 2. A comparison of the peak position with the value of the Compton edge gives a calibration of about 20 kev/volt. The resolution at higher energies compares with that found by Bird and Burch, i.e., a half-resolution for Co^{60} of 21%,† but the resolution of the low-energy peaks is poorer. The half-resolution for both I^{131} and Cs^{137} is about 50%. This may result from nonuniformities in the 16-in. photomultiplier cathode surface, but a more reasonable explana-

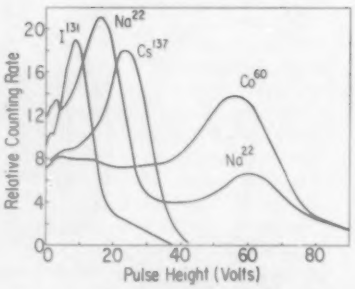

FIG. 2. Differential pulse-height distributions obtained with plastic scintillator. The peaks [E_c(max)] are 0.34 Mev for Na^{22} (Compton edge from annihilation radiation), 0.49 for Cs^{137}, 1.0 for Co^{60} and 1.02 for Na^{22} (Compton edge from 1.28-Mev γ-ray)

Comparison of NaI and Plastic Scintillators

Property	*16-in. dia. × 8 in. plastic*	*4 in. × 4 in. NaI*
Geometric efficiency 1 meter from sample with NaI as unity	16	1
Sample on center of scintillator face	50%	50%
Absorption efficiency (1 Mev)	75%	90%
Resolution (½ width, 1.25 Mev)	21%	4.5%
Fraction of counts in Compton or photopeak	50% (within 2 half resolutions of Compton peak)	30% (within full photopeak)

* Pilot Chemical Co., Watertown, Mass.

† Bird and Burch have defined the half-resolution of Compton spectra as the ratio of the energy interval between the peak of the distribution and the point at the high-energy side at which the intensity is decreased by one-half to the absolute energy value of the peak.

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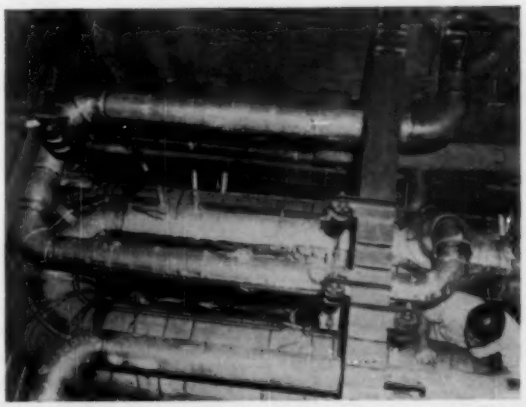

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 68

tion is the size of the scintillator. As the size increases, the possibility of multiple Compton interactions increases, and such events would tend to broaden the single-event Compton distribution. Eventually the Compton edge would disappear and a total-absorption peak would be seen. Although no total-absorption peak is evident in our spectra, the broadening of the low-energy lines is probably due to multiple Compton events.

Background measurements were made with an additional 8-in. iron lid on the shielding assembly. At baseline cutoffs of 500, 200, 100 and 50 kev, integral background counting rates were obtained of 4,180, 5,680, 9,000 and 12,500 cpm, respectively. A differential scan of the background failed to reveal any noticeable peaks. The background counting rate of this system compares very favorably with that of other systems using large amounts of scintillating material (4). Of particular interest is the relatively low background counting rate at energies as low as 50 kev.

To investigate further the uniformity of the scintillator and photomultiplier, spectra were taken with a source of Co^{60} at various positions on the surface and sides of the block of scintillator. The spectra so obtained were virtually identical. This observation as well as the shape of the spectra leads us to believe that the light production and collection are fairly uniform throughout the scintillator. Studies are currently underway on the uniformity of the photomultiplier and the possibility of using several 5-in. photomultiplier tubes for light collection.

* * *

This work was supported by the U. S. Atomic Energy Commission and the U. S. Public Health Service.

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Improved Master-Slave Manipulator Hand

By W. H. LEITH
E. I. du Pont de Nemours & Company
Savannah River Laboratory
Aiken, South Carolina

A new hand has been developed for the Argonne-type master-slave manipulators in use at the Savannah River Laboratory. It offers many advantages over its predecessor.

An innovation in the hand is the flexibility provided by detachable fingers (Figs. 1 and 2). The fingers, attached with snap-on fittings, are easily removed remotely in a high-level cell by means of the parking fixtures shown in Fig. 1. Tools such as scissors, knives and screwdrivers may be substituted.

All moving parts of the hand are integrated with the slave arm through direct mechanical linkage. This improves the precision of manipulation. To increase the gripping force, an increased mechanical advantage, a larger cable and pulley system, and a more rugged parallel linkage are incorporated. The new hand will undergo six times as many closures under a normal load as would the old hand.

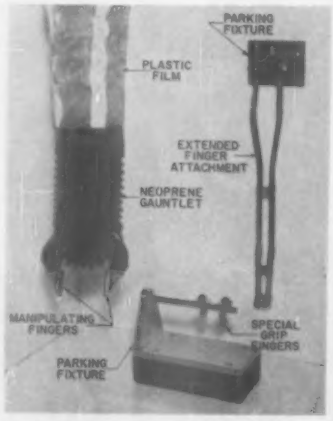

FIG. 1. Manipulator hand and arm are protected by gauntlet against contamination. O-rings seal the gauntlet at fingers. Parking fixtures are used for changing fingers

An important advantage is the protection afforded moving parts of the hand against contamination by the gauntlet. This facilitates making repairs. The only parts that are contaminated are the stainless-steel fingers, which are easily replaced. Because the hand is now integral with the arm, it is possible to protect the entire arm from the gauntlet to the cell wall

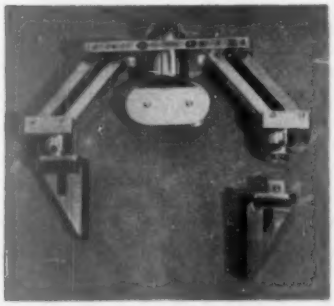

FIG. 2. Manipulator hand with one snap-on finger detached

with a plastic film. When the manipulator is removed from the cell, it slips out of the gauntlet easily.

The initial cost of the hand is reduced by about 35% compared with conventional designs, and the cost of replacing the parts exposed to contamination is 90% less. The cost of decontaminating the hands for repair is virtually eliminated, and the cost of the fixture used to remove the fingers is small.

The hand is now standard on all new SRL manipulators. It is commercially available from a manipulator manufacturer.

* * *

The information contained in this report was developed during the course of work under contract AT(07-2)-1 with the U. S. Atomic Energy Commission, whose permission to publish is gratefully acknowledged.

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Charging for Test-Reactor Space

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Physics Department, North Carolina State College, Raleigh, North Carolina
and M. A. SCHULTZ
Westinghouse Electric Corp., Pittsburgh, Pennsylvania

With the coming of age of the commercial-testing reactor industry, we feel it is important to re-examine the basis of the charges made for space in irradiation facilities. At present, in government-owned reactors, testing space is made available to commercial customers at a dollar charge per unit of ambient thermal *nvt* per unit volume occupied. For example, in the MTR the current charge rate is simply $\$55/10^{20}$ (thermal) nvt/in^3. Although there are many complex factors to be considered in developing a rate structure, it should be possible to develop one that is more rational, fairer.

Rate Considerations

In a competitive commercial economy, one assumes that a customer should be able to select a given radiation service at the lowest cost. This premise must be consistent with such nontechnical problems as availability of space and timing.

The type of test determines the location of a sample in the reactor. If the customer's problem is testing some form of fuel to be used in a thermal reactor, he desires a large quantity of thermal neutrons in his irradiation space and he isn't particularly concerned about the fast-neutron flux existing in this space. On the other hand, if the problem is one of radiation damage to a structural material, the designer wants information on how the fast neutrons affect his structure, knowing that thermal neutrons have little effect on most structural materials.

For today's U^{235}-fueled testing reactors, such as MTR, WTR, GETR and ORR, the fast-neutron flux is very high in the core and falls off in the reflector. The thermal-flux level is high both in the core and in the reflector peak. This situation is indicated in Fig. 1 showing relative fast and thermal fluxes for a typical cylindrical U^{235}-fueled reactor. Thus, the customer for large quantities of

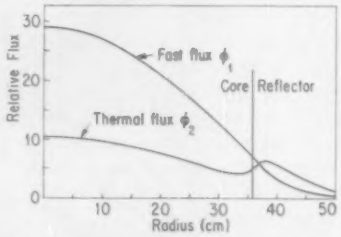


FIG. 1. Typical radial flux distributions for cylindrical reactor

fast neutrons generally prefers testing space in the reactor core. Clearly a pricing scheme based only upon thermal *nvt* does not reflect this added desirability and usefulness of the core space. It seems reasonable that a distinction should be made between fast and thermal neutron charges to allow the user to select the most economical placement of his test sample. However, what the relative costs of fast flux and thermal flux should be is not clear.

Another improvement concerns the reference flux distribution on which irradiation rates are based. The flux that exists in any given spot in a testing reactor changes with time as the core depletes, changes with control-rod position and changes with loading. The fairest situation would be one in which a customer actually paid for the number of neutrons he used, that is, the number of neutrons his sample absorbed. But this type of charge would dictate an actual measurement of thermal and fast flux at every sample point in the reactor.

The presently used system of charging on an ambient thermal-neutron-flux basis is a good first approximation in that, if some reference must be established, the ambient flux before any samples are inserted in the reactor is a simple, easily understood one. In other words, the customer at present does not pay an actual use charge, but rather he pays for the privilege of inserting his sample in a given flux ambient regardless of how much he disturbs this flux locally or changes its general level.

A somewhat fairer basis would be to select reference flux levels closer to the actual average values that individual samples would receive during the irradiation rather than pre-insertion levels. A better reference flux for rate purposes might be the flux distribution resulting from a uniformly distributed sample absorption throughout the core and reflector.

Most irradiation samples placed in a testing reactor tend to reduce the available reactivity. Consequently, the reactor might require additional fuel over that needed for criticality purposes when no samples were present. The reactor owner is of course aware of this fact but is committed to provide irradiation services with samples in the reactor. He, therefore, cannot claim any premium charges for this added fuel. However, on an individual sample basis, he might properly assess incremental charges for absorbers that make it impossible to load the reactor fully with samples or that force him to provide added fuel in the core above a normal value. Added fuel reflects in costs two ways. First, there is the cost of the added fuel itself. However, the loss of revenue from the testing space that is filled with the extra fuel can be far greater.

Still another factor that might be taken into account in pricing formulae is that in some reactor locations a large absorption cross section in a sample not only creates a thermal-flux depression in the sample itself but also depresses the thermal flux in adjacent irradiation spaces. Thus, these adjacent spaces become less effective or valueless for other experimenters. Peculiar effects may also be created in adjacent holes by samples with large resonance absorptions, thus disturbing the energy distribution obtained by neighboring samples.

Finally there is the customer desiring to irradiate a test sample containing fuel. In some instances this customer actually gives more neutrons back to the reactor than he absorbs. This should, in fairness, be given credit for these neutrons.

Physical Formulae

A logical approach toward developing a completely useful formula that includes the above considerations might begin as follows:

Consider a sample having a volume V being irradiated in a test reactor for time t at a location r. The total charge $C(r)$ will be the sum of a number of elements.

$$\vec{C}(r) = \vec{C}_s(r) + \vec{C}_p(r) + \vec{C}_a(r) - \vec{C}_u(r) \quad (1)$$

The first term, $\vec{C}_s(r)$, refers to a basic "sample" charge taking into account the fact that both fast and thermal fluxes should be considered on an independent charge basis. Its form would be

$$C_s(r) = [\vec{\varphi}_1(r)c_1 + \vec{\varphi}_2(r)c_2]Vt \quad (2)$$

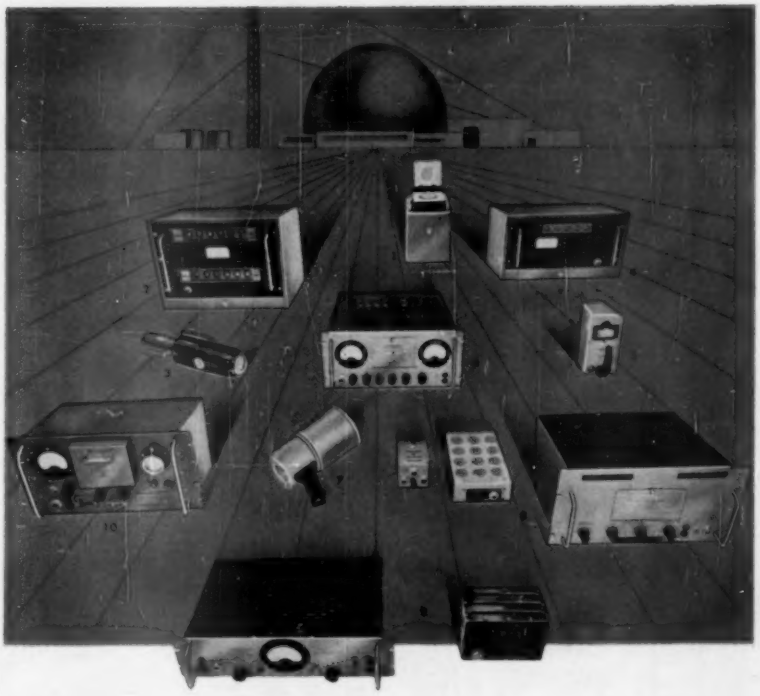
where $\vec{\varphi}_1(r)$ is the fast flux, $\vec{\varphi}_2(r)$ the thermal flux and c_1 and c_2 are unit volume charges per unit of fast and thermal nvt.

Reactor perturbation. The second $\vec{C}_p(r)$ is a "perturbation" term including all perturbations with self-shielding implied. It is used to assess incremental charges for absorbers that make it impossible to load the reactor fully with samples. The perturbation effect can be expressed in terms of the adjoint importance functions φ_1^+ and φ_2^+, which determine the result of removing a fast or thermal neutron at a point. One form of C_p might be

$$\vec{C}_p(r) = (\varphi^+ P \varphi)c_p\, Vt \quad (3)$$

where φ^+ and φ are the adjoint and ordinary flux matrices, c_p is a proportionality constant, and P is a perturbation-function matrix depending, among other things, on the change in fast-removal and thermal-absorption cross sections $\delta\Sigma_1$ and $\delta\Sigma_2$ caused by the sample. Figure 2 shows φ_1^+ and φ_2^+ for the reactor of Fig. 1.

The matrix product of $\varphi^+ P\varphi$ is obtained from two-group theory by considering the expression for reactivity caused by changes in fast neutron production and removal, resonance capture and thermal absorption. The reactivity due to changes in macro-



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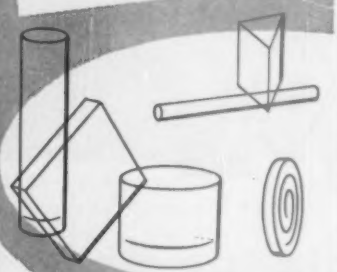

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Test Reactor Charges

This article starts on page 72

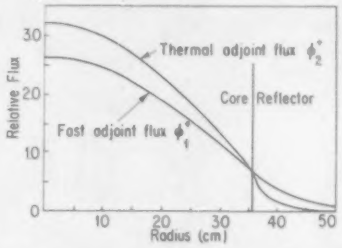

FIG. 2. Adjoint flux distributions corresponding to physical flux distributions shown in Fig. 1

scopic cross section is

$$\rho = \frac{\delta k_e}{k_e} = \frac{\int \varphi^+ P \varphi \, dV}{\int \eta f \Sigma_2 \varphi_1^+ \varphi_2 \, dV} \qquad (4)$$

where according to two-group theory

$$\varphi^+ P \varphi = \varphi_1[\varphi_2^+ \delta(p\Sigma_1) - \varphi_1^+ \delta\Sigma_1] + \varphi_2[\varphi_1^+ \delta(\eta f \Sigma_2) - \varphi_2^+ \delta\Sigma_2] \qquad (5)$$

If p is $\sim$1, as in the reflector or in a highly enriched core and $\eta f \Sigma_2$ is not significantly changed with the insertion of an absorber, then

$$\varphi^+ P \varphi = (\varphi_2^+ - \varphi_1^+)\varphi_1 \delta\Sigma_1 - \varphi_2^+ \varphi_2 \delta\Sigma_2 \qquad (6)$$

The first term of the right-hand side of this equation describes the net effect of a removal of neutrons from the fast group (a loss) and a supply of neutrons to the thermal group (a gain) appropriately weighted by the adjoint functions. The second term is readily seen to be the thermal-adjoint-weighted change in absorption rate. The perturbation-term form of Eq. 5 or Eq. 6 may be used depending upon whether the ultimate formula includes resonance or fission source effects.

Knowing that energy-distribution perturbations can be handled by Eq. 5 if desired, we can proceed with the simpler form and find the perturbation factor

$$\vec{C_p}(r) = [(\varphi_2^+ - \varphi_1^+)\varphi_1 \delta\Sigma_1 + \varphi_2^+ \varphi_2 \delta\Sigma_2] c_p V t \qquad (7)$$

where absolute values of the cross section changes are implied.

Adjacent shielding. The third term in Eq. 1, $\vec{C_a}(r)$, is related to the flux depression in *adjacent* samples. This term may be handled in a widely varying manner. One method is indicated in the present MTR published schedule for commercial irradiations: "Irradiations involving materials of such high macroscopic absorption cross section as to create excessive shadowing effects in adjacent facilities will, in addition to the charge for the space actually occupied, be charged at the standard rate for any of these facilities that have to be left vacant because of such shadowing."

Another approach considers the following argument. For any sample inserted in the reactor, the thermal-flux distribution nearby can be evaluated as φ_{2a}, a value less than the undisturbed φ_2. A charge can then be made proportional to the drop $\varphi_2 - \varphi_{2a}$ and the adjacent affected volume. Then

$$\vec{C_a}(r) = (\varphi_2 - \varphi_{2a}) c_2 V_a t \qquad (8)$$

where c_2 is the previous thermal-flux unit charge of Eq. 2 and V_a is the adjacent irradiation volume affected.

The value of φ_{2a} for a black sample may be calculated on the same basis as if it were a control rod. Grey sample effects can be determined with existing computing-machine codes. In any event, the farther away the adjacent sample hole is located, the less will be the depression in it. In no case will the adjacent-cell flux be completely reduced to zero.

A sample calculation using the reactor constants of Figs. 1 and 2 indicates that for a 1¼-in.-diameter black sample, the flux in the center of the next adjacent hole at a center-to-center distance of 3⅛-in. would be reduced only 5.3% from the undisturbed thermal flux. However, if this particular black sample were inserted in a hole at the center of a cluster of say six adjacent holes, each one of the six adjacent holes would suffer the 5.3% flux depression. From an overall point of view, this would be equivalent to a flux depression of 31.8% in one adjacent hole.

There are, of course, many possible flux depressions with different material combinations. Figure 3 indicates adjacent-cell edge depressions for two samples having different absorption cross sections. The charge $\vec{C_a}(r)$ would then be calculated from this type of graph and would have a value ranging from zero to the full equivalent adjacent space charge as specified in MTR schedule.

Fuel credit. The last term of Eq. 1, $\vec{C_u}(r)$, is the credit given for the use of a customer's fuel. An elementary way of handling this term is for the

operator to add up his direct fuel costs and to give credit on an equivalent gram-for-gram basis.

For example, let the cost to the reactor operator of one fuel element containing y grams of U^{235} be x dollars. This cost might include uranium conversion, fuel-element fabrication, interest charges, normal depletion, reprocessing, shipping and any other charges directly associated with the life cycle of one fuel element. Then the worth of equivalent U^{235} fuel to the operator is x/y dollars/gram. Thus if a customer's sample contains z grams of equivalent fuel placed in the same effective position as the fuel element, the customer is entitled to a credit of xz/y dollars. He still would expect to pay for his normal irradiation service, however.

Determining Constants

$\vec{C}_a(r)$ and $\vec{C}_u(r)$ are special use situations not necessarily applicable to all irradiation samples. In addition, $\vec{C}_u(r)$ is directly obtainable from a chart once an equitable value has been set on a gram of fuel. $\vec{C}_a(r)$ is also simply available from charts once the basic value constants c_1, c_2, and c_p have been determined from other considerations. We can, therefore, place $\vec{C}_a(r)$ and $\vec{C}_u(r)$ aside and examine possible interrelationships between c_1, c_2 and c_p.

Two criteria may be used for setting these three parameters. These are the total income required and the propriety of the perturbation charges. The overriding fact that takes precedence above all others in a rational approach is that C_T, the total income, must match reactor operating costs plus profit. We can now integrate Eq. 1 over the entire sample-containing volumes of the core and the reflector, neglecting C_a and C_u. Then

$$\frac{C_T}{V_T t} = \bar{\varphi}_1 c_1 + \bar{\varphi}_2 c_2 + \overline{\varphi^+ P \varphi} c_p \quad (9)$$

C_a may be neglected as its charge is included in the entire volume whether its space is used or not. C_u is neglected simply because in a practical reactor it is apt to be small.

In Eq. 9, the average fluxes over the whole reactor sample space appear along with the nominal poison that would be tolerated by the reactor operation. This nominal poison can be evaluated numerically from a reference amount of fuel that is needed,

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Test Reactor Charges

This article starts on page 72

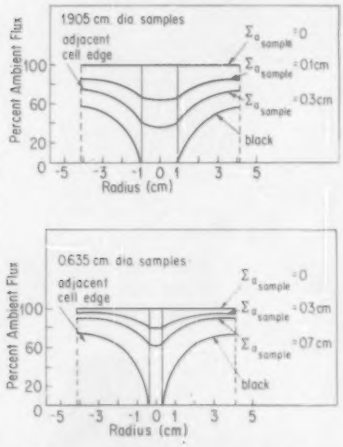

FIG. 3. Flux depression in adjacent test cell caused by neutron-absorbing test specimen as a function of absorption cross section and specimen diameter

say for transfer purposes, and the known distributed poison in the core that renders the loaded reference reactor critical. Or

$$\varphi^+ P \varphi = \overline{\varphi^+ \delta\Sigma_p \varphi_2}\, \frac{V_s}{V_t} \qquad (10)$$

where the average on the right side of the equation is taken over the core only.

We have thus established as a basic reference the normally distributed poisoned core rather than an ambient unpoisoned one. Perturbations greater than this reference may now be susceptible to added charges.

The maximum possible perturbation charge should be limited to a reasonable value in relation to the basic irradiation charge. Two further criteria are proposed. We define two new parameters c_{p1} and c_{p2}, which represent, respectively, the unit cost factors associated with fast and thermal perturbations. Using these constants, Eq. 7 becomes

$$\vec{C}_p(r) = [\varphi_1(\varphi_2^+ - \varphi_1^+)\delta\Sigma_1 c_{p1} + \varphi_2\varphi_2^+\delta\Sigma_2 c_{p2}]Vt \qquad (11)$$

The first criterion is that the maximum charge from the contribution of each perturbation term should be no larger than the use charge for the basic neutrons themselves. Or

$$[\varphi_1(\varphi_2^+ - \varphi_1^+)\delta\Sigma_1]_{max} c_{p1} \leq [\varphi_1]_{max} c_1 \qquad (12)$$

and

$$[\varphi_2\varphi_2^+\delta\Sigma_2]_{max}\, c_{p2} \leq [\varphi_2]_{max} c_2 \qquad (13)$$

The second criterion is that the maximum perturbation charges be of the same order of magnitude so as not to discriminate against users of either fast or thermal irradiations. Hence,

$$[\varphi_1(\varphi_2^+ - \varphi_1^+)\varphi\Sigma_1]_{max} c_{p1} = [\varphi_2\varphi_2^+\delta\Sigma_2]_{max} c_{p2} \qquad (14)$$

In a given reactor having fixed reference flux distributions similar to Figs. 1 and 2, the problem is resolved by determining the values of $(\delta\Sigma_1)_{max}$ and $(\delta\Sigma_2)_{max}$.

In a water-moderated reactor, the largest $\delta\Sigma_1$ is that corresponding to the replacement of water, essentially the best moderator, with a heavy metal for which Σ_1 can be considered zero. $(\delta\Sigma_2)_{max}$ may be evaluated from transport theory from which

$$(\Sigma_2)_{max} \simeq 1/2r_s \qquad (15)$$

where r_s is the radius of a cylindrical sample.

For any given set of reactor constants, Eqs. 12–14, may be solved and relationships obtained between c_1, c_{p1}, c_2, and c_{p2}. Now it remains only to set a value of total income needed for successful plant operation and a proposed formula for any specific sample volume becomes

$$C = [\varphi_1 c_1 + \varphi_2 c_2 + Ac_1\varphi_1(\varphi_2^+ - \varphi_1^+)\delta\Sigma_1 + Bc_2\varphi_2\varphi_2^+\delta\Sigma_2]V_s t \qquad (16)$$

where A and B are known numbers and V_s is the sample volume. The adjacent depression term and the fuel credit term may be added in separately if desired. It is recognized that Eq. 16 contains a degree of arbitrariness in the selection of the two criteria that led to its formulation. Other arbitrary criteria can be selected and values assigned to A and B directly without disturbing the form of the logic.

Approximate Formulae

Equation 2 is quite usable as is, in that for a given reactor, φ_1^+ and φ_2^+ are as theoretically easily available as φ_1 and φ_2. Some simplification may be called for in practical neutron marketing problems. For example, the third term of Eq. 16 in given practical situations appears to be small in comparision with the fourth term. From Fig. 2, $(\varphi_2^+ - \varphi_1^+) < \varphi_2^+$, c_1 is usually smaller than c_2 and $\delta\Sigma_1$ is apt to be smaller than $\delta\Sigma_2$ in practical irradiation samples. Therefore, we neglect this term and Eq. 16 becomes

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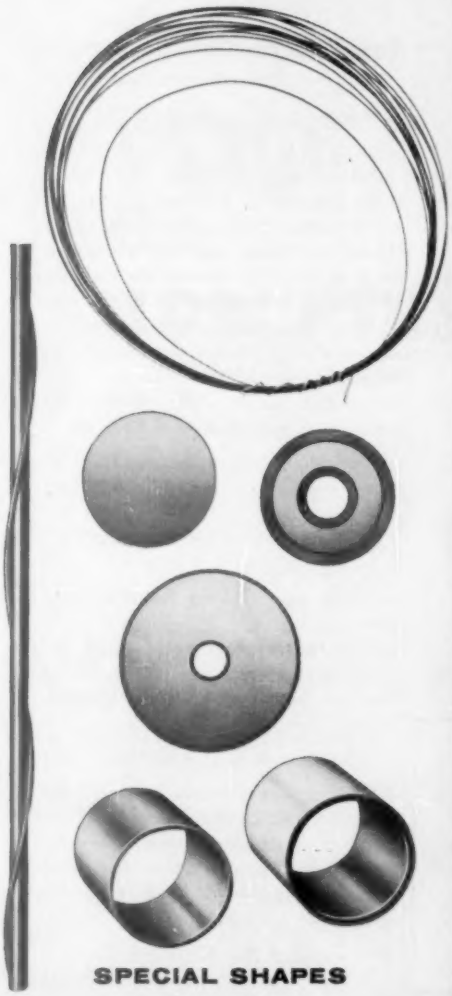

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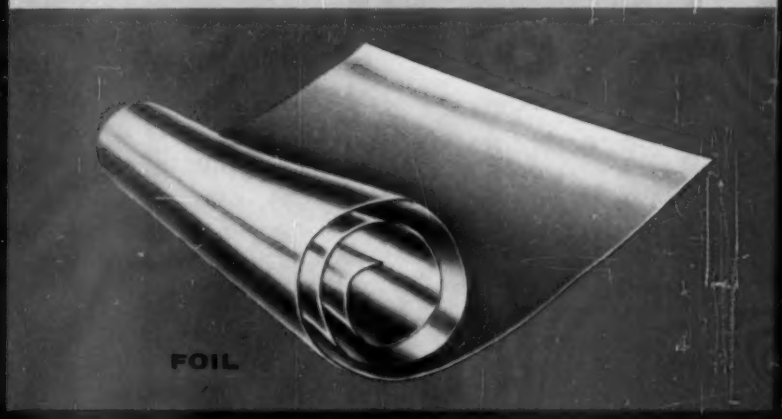

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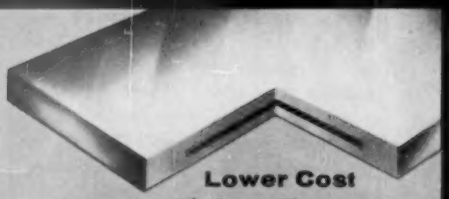

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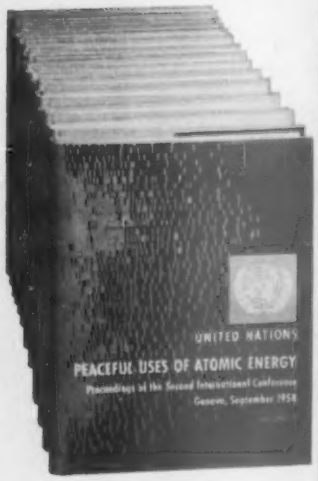

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Test Reactor Charges

This article starts on page 72

$$C = [\varphi_1 c_1 + \varphi_2 c_2 + B c_2 \varphi_2 \varphi_2^+ \delta\Sigma_2] V_a t \quad (17)$$

Another approximation can be made with reasonable accuracy. That is, φ_2^+ is essentially of the same form as φ_1. Therefore, the φ_1 distribution may be used in place of the φ_2^+ distribution provided it is multiplied by a constant. If this substitution is made using the curves of Figs. 1 and 2, for example, an error of only 10% occurs over the entire distribution. The effect of the constant simply changes B to B_1 or

$$C = [\varphi_1 c_1 + \varphi_2 c_2 + B_1 c_2 \varphi_2 \varphi_1 \delta\Sigma_2] V_a t \quad (18)$$

or

$$C = [\varphi_1 c_1 + \varphi_2 c_2 (1 + B_1 \varphi_1 \delta\Sigma_2)] V_a t \quad (19)$$

which is again a very useful working formula.

The simplification process may continue for reactors in which $c_1 \ll c_2$, and the first term of Eq. 19 is neglected. Then

$$C = [\varphi_2 c_2 (1 + B_1 \varphi_1 \delta\Sigma_2)] V_a t \quad (20)$$

To this formula may be added the two special situations C_a and C_u. The result is a simplified approximate relationship for some reactors that takes into consideration all of the problems outlined in the introduction

$$C = \varphi_2 c_2 (1 + B_1 \varphi_1 \delta\Sigma_2) V_a t + C_a - C_u \quad (21)$$

Despite the liberal approximations made, Eq. 21 has the proper physical form. First, there is a basic thermal-neutron use charge, $\varphi_2 c_2$, corresponding to current practice. This basic charge is increased to include the effects of an enhanced fast-neutron spectrum. Thus out in the reflector the incremental charge for fast neutrons will be very small. Only in the core will the increment be appreciable. In addition, the added charge for high-cross-section samples essentially occurs only in the reactor core. This charge distribution is also proper because a high-cross-section sample placed in the core affects reactivity much more than a similar sample placed out in the reflector. The adjacent hole-disturbance change is clearly desirable as is the fuel rebate. We feel that the use of any of the formulae from Eqs. 16 through 21 will result in a rate structure for irradiation service in commercial testing reactors that are rationally derived and fair to both the user and reactor operator.

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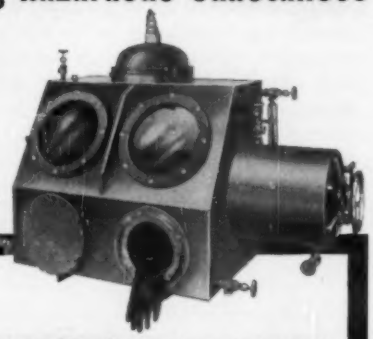

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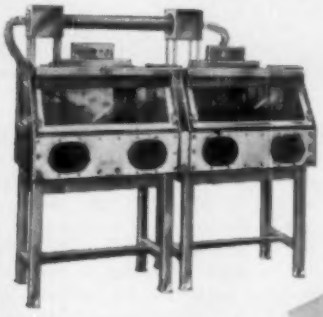

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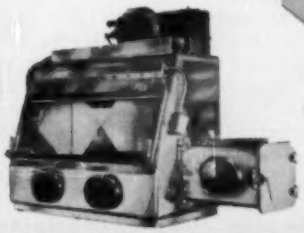

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U. S. Interest Grows in Gas-Cooled Designs

Not much more than a year ago, "gas-cooled power reactor" was a term not to be found in the U. S. reactor designer's vocabulary; but, at the AEC's gas-cooled reactor information meeting this October, it was clear that the gas-cooled concept has overnight become a strong contender in the U. S. program.

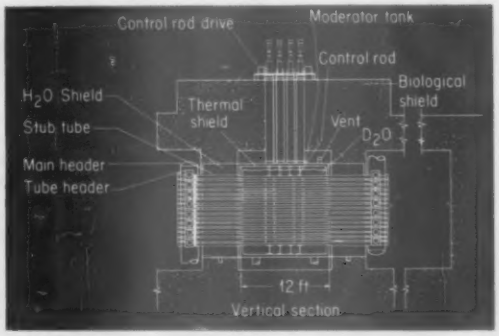
During the conference, host A. Weinberg, Director of ORNL, confessed to a substantial shift in emphasis at ORNL from homogeneous reactor systems to the gas-cooled approach —as a result ORNL is presently at least "half gas cooled." In addition to ORNL, four private concerns* described gas-cooled-reactor design studies†, already backed up in some measure with experimental development work, and outlined plans for further testing.

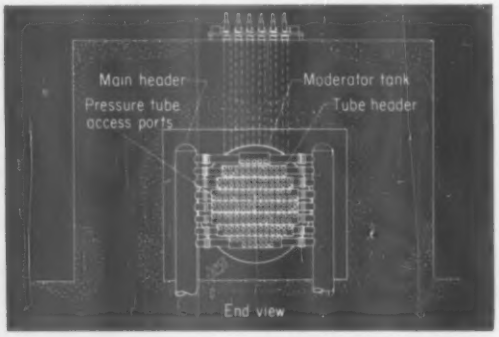
In general the designs call for slightly enriched UO_2 cores operating at gas-outlet temperatures of over 1,000° F. Except for the General Nuclear Engineering design (see box), graphite moderator is the universal choice. Although CO_2 as a coolant has some advantages, at the outlet temperatures of interest (from 1,000° F on up

Continued on page 118

* Kaiser Engineering–ACF Industries, Sanderson and Porter, General Atomic and General Nuclear Engineering.

† For a description of the recently proposed General Atomic concept see p. 17.





General Nuclear Engineering's D_2O Gas-Cooled Reactor

Possibly the first gas-cooled commercial power reactor to go critical in the U. S. will be the 50-Mw(e) D_2O pressure-tube plant designed by General Nuclear Engineering for use by Florida Power and Tampa Electric. Scheduled to start operation in 1963, the reactor is to function as a prototype for a future full-scale 200 Mw(e) plant. The prototype is expected to prove out directly all the design features except the physics. (Extrapolation will be needed in this area since, while the full-scale design will use natural UO_2, the smaller prototype requires 1.84% enriched fuel.) The aim in both the prototype and full-scale plants is to build a reactor that has simultaneously high specific power and steam-cycle efficiency and good neutron economy.

The high exit gas temperature (1,000–1,050° F) will make possible steam conditions and cycle efficiencies comparable to those used in the most modern conventional plants. High specific power and neutron economy are achieved by using high-pressure coolant (500 psi), heavy water as the moderator and low-absorption-cross-section materials in the core.

The net plant thermal efficiency will be about 33%. The energy in the moderator is used for the initial stage of feedwater heating. The pressure drop in the primary loop will be about 30 psi, which requires 4 Mw of pumping power. The plant will have two loops, each with a separate heat exchanger, blower and piping.

The prototype core (see figure) contains 178 horizontal Zr pressure tubes arranged on a square 8-in lattice. D_2O moderator fills the space outside the tubes and CO_2 coolant gas flows over the outside surface of the fuel bundles, which are loaded inside the tubes. The coolant gas is supplied to the tubes by seven horizontal manifolds, each of which feeds two rows of tubes. The manifolds take off two large vertical main headers.

A fuel-handling machine clamps to the pressure-tube-access-port plug to replace fuel with the system at full pressure.

The basic building block of the fuel assembly is a stainless-steel tube loaded with cylindrical enriched UO_2 pellets with welded end closures. Nineteen of these rods are assembled to form a bundle and about eight such bundles will make up a full pressure-tube load. To hold the center temperature below melting, the fuel-pellet centers are cored. When at operating temperature and pressure, the cladding will collapse onto the UO_2.

Since stainless-steel cladding would not be suitable for the large-scale reactor, it is planned to use the reactor to test lower-cross-section clad materials (such as Be) when they have been developed.

Since the average gas temperature is about 750° F while the D_2O temperature will be about 220° F, insulation must be provided between the two regions. An arrangement of two ceramic lines separated by a CO_2 gas space is expected to keep the gas-to-moderator energy loss down to about 2.8 Mw.

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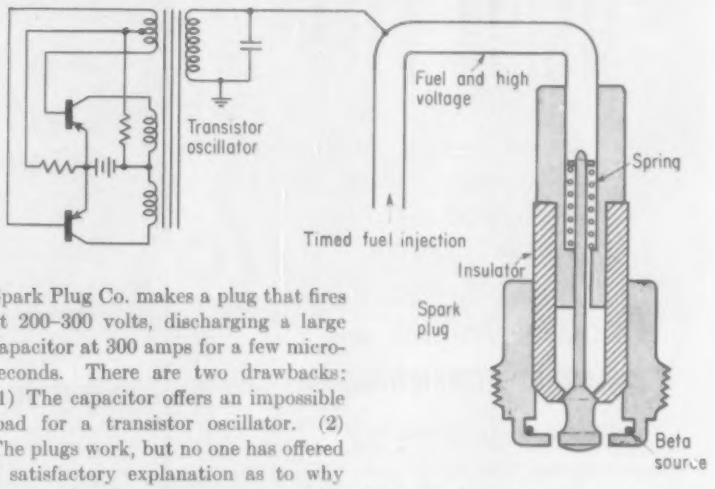
APPLIED RADIATION

Can Beta Rays Make Better Spark Plugs?

When better automobile engines are built, radiation may help to make them operate. Better engines may demand fuel injection; fuel injection suggests electronic ignition; electronic ignition systems would like to work into low-voltage spark plugs; and low-voltage plugs may demand preionization of their gaps. An alpha or beta emitter would be a good means of preionizing the gap if there is a good way to put the radionuclide into the plug.

The figure shows a system that is under development. Both fuel and the electrical potential to fire it are conducted to the spark plug through a hollow, insulated injection line. The fuel remains liquid until it is shot into the combustion chamber in response to a cam-timed pressure pulse. Impact with air molecules already in the chamber shreds the fuel droplets and causes atomization. Meanwhile the transistor oscillator supplies ignition sparks. Such an oscillator is not usually a brute-force device; it will work best if it fires a low-voltage gap with fairly loose coupling to it.

Low-voltage spark plugs are already in use. For example, the Auburn Spark Plug Co. makes a plug that fires at 200–300 volts, discharging a large capacitor at 300 amps for a few microseconds. There are two drawbacks: (1) The capacitor offers an impossible load for a transistor oscillator. (2) The plugs work, but no one has offered a satisfactory explanation as to why they work. Thus it is hard to modify them for electronic systems.



Perhaps adaptation is impossible. The plugs use a low-conductivity shunted surface in place of the nearly perfect insulators of usual plugs. Some think that the reason they fire at low potentials is that the conductivity provides enough ohmic heating to provide some preionization. If this explains the operation, the power required would preclude electronic operation.

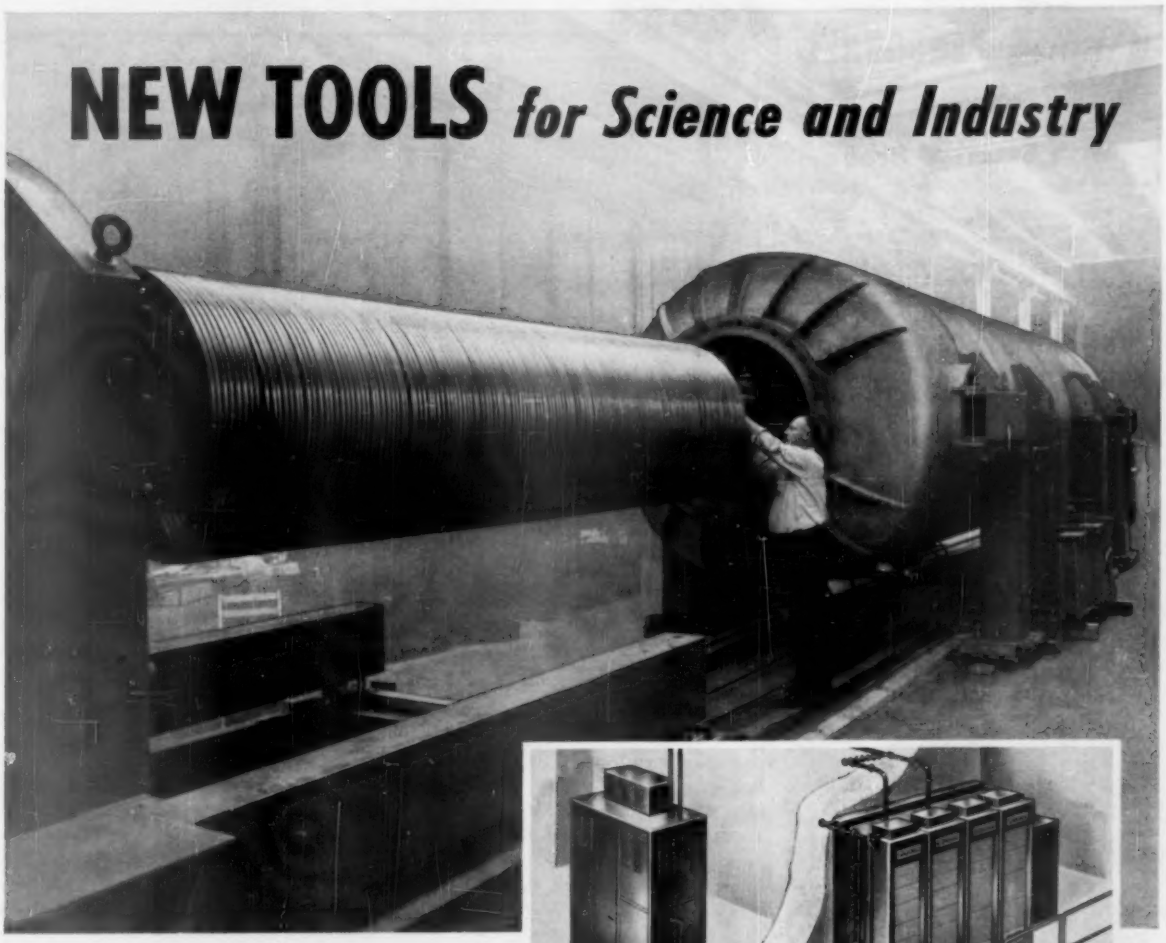
How to use radiation is also a problem. From the chart of the nuclides you must select beta and alpha emitters with usable energies and half-lives. Then you must drop the ones with gamma rays that demand shielding when the plugs are on storage shelves. Many of the elements that are left won't behave well at combustion-chamber pressures and temperatures. And finally you must find something with a chemical behavior that makes it cheap and easy to handle. What are your suggestions?

Plating Tl^{204} on nickel wire and protecting it with a nonradioactive metal may be a feasible method (NU, Dec. '54, p. 53). The prepared wire would be coiled into springs, cut into circles, and inserted into the mouth of the spark plug for beta-ray preionization.

Automatic self-timing is an additional possibility with such a plug. Compression itself will increase the ion density in the gap and might successfully initiate breakdown. The result would be a d-c ignition system unencumbered by timers, spark coils, or distributors. A small transistor oscillator-rectifier supply would furnish the d-c potential. Timing would be taken over by the injection mechanism, which has to be properly timed in any case.

By one engineer's estimates this ignition system would be not only simpler but also much cheaper than present ones. Its replacement cost might be as little as $20, which is to be compared with ~$78 for present systems.

NEW TOOLS *for Science and Industry*



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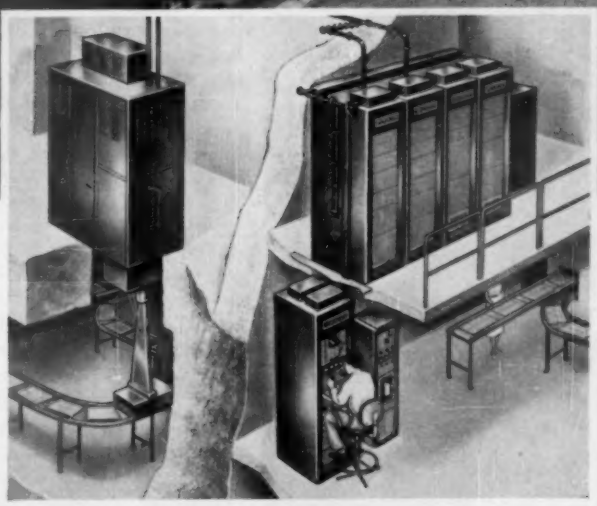

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Model ALM-2X
Hand & Foot Monitor

Model ALM-1X
Hand Monitor

In addition to the models shown, T/A also manufactures Hand & Shoe Counters employing the register read-out principle based on Hanford designs.

Write for Bulletin No. 161

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BOOKS

The Geneva Presentation Volumes

A high point in U. S. participation at Geneva was a series of 13 volumes (see above), specially bound and inscribed sets of which were presented to the delegations. Twelve of the volumes, prepared under AEC supervision and published by Addison-Wesley (Reading, Mass.), are described below. The thirteenth ("The Physical Theory of Neutron Chain Reactors," by A. Weinberg and E. Wigner, U. of Chicago Press), will be reviewed in a later issue.

Fluid Fuel Reactors, edited by J. Lane, H. MacPherson, F. Maslan (xxii + 979 pages, $11.50). This summarizes the work done in the U. S. in the last ten years on fluid fuels. The three parts deal with aqueous-homogeneous, fused-salt and liquid-metal (Bi-U) systems. Each part includes reactor-physics calculations, fuel-solution properties, metallurgy, reactor-design considerations and economics.

Project Sherwood, the U. S. Program in Controlled Fusion, by Amasa S. Bishop (x + 216 pages, $5.75). The author reviews basic principles of controlled fusion and then the technical and administrative history of the Sherwood projects. The fundamental ideas and the principal difficulties behind each of the approaches are explained without mathematics. Appendices include tabulations of experimental models and glossaries.

Radiation Biology and Medicine, edited by W. Claus (xxii + 944 pages, $11.50). This volume covers the field with "selected reviews" by 56 authoritative authors. Subjects range from a brief history of radiation biology to the medical uses of reactors. It includes physiological and biochemical responses to radiation, tracer applications in medicine and agriculture, instrumentation, dosimetry and mathematical biology.

Sodium Graphite Reactors, by C. Starr and R. Dickinson (xii + 288 pages, $6.50). This volume is almost a handbook of the Sodium Reactor Experiment (SRE); six chapters cover its description, nuclear characteristics, materials requirements, fuel, components and operation. The other two chapters introduce the system and describe large-scale concepts.

Solid Fuel Reactors, edited by J. Dietrich and W. Zinn (xvi + 864 pages, $10.75). Basic concepts, present state of development, and technical and economic prospects in the U. S. are reviewed for five projected solid-fuel power-reactor types: fast-breeder, heavy-water, gas-cooled, organic-moderated and plutonium-recycle reactors. Analyses are provided that are intended to indicate the directions for future work.

Shippingport Pressurized Water Reactor, by personnel of AEC, Westinghouse Electric Corp. and Duquesne Light Co. (xii + 600 pages, $9.50). Contents range from reactor design to site selection and construction details. Chapters cover the testing program, waste disposal, components, shielding, hazards evaluations and water chemistry. The chapter on physics describes the advantages of the seed-and-blanket core concept at length.

Thorium Production Technology, by F. Cuthbert (xiii + 303 pages, $6.50). Cuthbert provides the essential information, from purification, through reduction, to fabrication of the metal. Extensive reference lists are included. Topics covered are properties of metal

and compounds, ore extraction, concentrate purification, reduction to metal, casting, fabrication, safety aspects and testing.

Physical Metallurgy of Uranium, by A. Holden (x + 262 pages, $5.75). The author has limited the discussion chiefly to uranium metal with only brief discussion of the alloys. Although the major part of the volume is devoted to the unirradiated metal, two chapters are included on the effects of radiation and thermal cycling. Topics include physical and chemical properties, grain growth, diffusion and metallic-fuel design.

Uranium Ore Processing, edited by J. Clegg and D. Foley (xi + 436 pages, $7.50). The first four chapters are concerned with the more common ores —mining, analysis and mineralogy. Succeeding chapters cover processing, from preliminary treatment to solvent extraction. Another chapter describes the operation of six domestic and foreign mills. The last two chapters discuss recovery from less common ores and health problems.

The Transuranium Elements, by G. Seaborg (xx + 328 pages, $7.00). This volume is an expansion of four Silliman Lectures presented at Yale University in 1957. It is, essentially, a history of the discovery and production of the transuranium elements through mendelevium. The author takes special care to list the names of the participating chemists and to describe their ingenious experiments.

U. S. Research Reactor Operation and Use, edited by J. Chastain, Jr. (xiv + 366 pages, $7.50). This volume covers reactor theory only enough to provide basic concepts and an understanding of some common terms. Design features, operating problems (administrative as well as technical), safety considerations and costs are discussed for a number of reactor types, including light water, heavy water, homogeneous and graphite.

Boiling Water Reactors, by A. Kramer (xi + 563 pages, $8.50). General principles and descriptions are given for various boiling-reactor cycles. A summary of experimental investigations and a chapter on the design of boiling systems follow. The remainder of the volume is mostly devoted to detailed description and discussion of existing reactors. Significant space is devoted to the EBWR, Vallecitos, ALPR and Dresden reactors.

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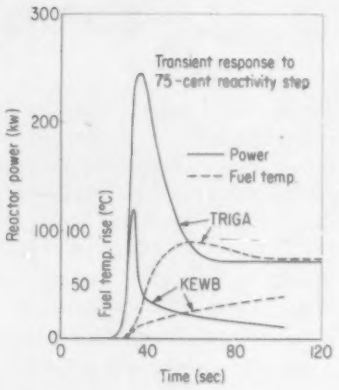


TRIGA vs KEWB

DEAR SIR:

The dynamic behavior of the TRIGA reactor, as described briefly in your "Nuclear Engineering" department (NU, Aug. '58, p. 116), is of particular interest to our Reactor Kinetics Group.

With respect to the maximum power attained, the energy released and the core-temperature increase following a step input of reactivity of 75 cents, our experiments indicate a rather substantial difference in the behavior of the TRIGA and a water-boiler-type reactor.

As shown on the comparison graph, the water-boiler reactor responds more favorably, from the viewpoint of all parameters considered. That is, the water boiler reaches only one-half the maximum power achieved by the TRIGA reactor, releases only about one-fifth the energy and undergoes a maximum fuel-temperature rise (allowing no heat loss to the core vessel) of only 40° C as compared with 90° C in the TRIGA excursion.

—J. W. FLORA and D. L. HETRICK
Atomics International
Canoga Park, Calif.

DEAR SIR:

At the time that it was decided to develop an inherently safe research reactor using solid homogeneous fuel-moderator elements, General Atomic was aware that large prompt-shutdown coefficients could be obtained in liquid-fueled reactors.

This type of coefficient has been well demonstrated by the KEWB experiments. However, the use of the solid homogeneous fuel-moderator elements developed by General Atomic provides a sufficiently large prompt-shutdown mechanism to limit transient-energy release, and it also precludes any release of radioactive fission products. This is a significant advantage of the solid homogeneous fuel-moderator reactor type.

It should be noted that the prompt-shutdown mechanism in the TRIGA reactor is characteristic of the moderating properties of the uranium-zirconium-hydride fuel-moderator elements. There is no expulsion of radioactive fuel material or water required from the TRIGA reactor core to provide the full shutdown effect from this inherent large prompt negative temperature coefficient.

In the water-boiler reactor, the prompt-shutdown mechanism results from the expansion of the fuel solution due to heating and void formation. Provision must be made to allow the escape of radiolytic gas and fuel solution from the core.

Since the brief report in NUCLEONICS, transient testing of the TRIGA reactor at General Atomic has been continued. At present, this reactor operates at a power level of 100 kilowatts and has been subjected to a 2.00-dollar (1.6% $\Delta K/K$) step reactivity insertion. In this transient, the reactor power increased to a maximum of 250 Mw on a 9.8-msec period. Immediately following the prompt power burst, power level was reduced to an equilibrium value of 200 kw.

In this experiment, the maximum fuel-temperature rise was limited to 400° C as measured at the center of the hottest fuel element. There was no boiling in the core and no disturbance of the shield water surface. In this maximum transient, the radiation dose that would have been received by an individual immediately over the top of the reactor shield-water tank would be about 20 mrem. These experiments are normally performed with personnel in the immediate vicinity of the reactor.

The uranium-zirconium-hydride fuel-moderator material used in the TRIGA reactor elements has been tested in the laboratory to 1,200° C, and test samples have been irradiated in the MTR to an equivalent fuel burnup in excess of 20% without evidence of damage. On the basis of these data, one concludes that the TRIGA reactor will be capable of routine operation at much higher transient power levels.

—R. S. STONE
General Atomic
San Diego, California

INDUSTRY NOTES

• **Atomic Associates,** Cambridge, Mass., has been appointed sales-service representative in the East and Midwest for the complete lines of Cary Electrometers marketed by **Applied Physics Corp.,** Monrovia, Calif.

• **Chromalloy Corp.** and **Chilean Nitrate Sales Corp.** have completed an exclusive licensing agreement that will bring expanded production and increased research and development by Chromalloy of an ultrapure form of chromium for use in reactor alloys. The almost-pure metal is produced under an iodide-chromium process developed by **Battelle Memorial Institute.**

• **NRD Instrument Co.,** subsidiary of **Nuclear Corp. of America,** has followed the shift of its manufacturing facilities from St. Louis, Mo., to Denville, N. J., with the transfer of its sales offices to the same location.

• **Hydrometals, Inc.,** New York, has acquired exclusive, world-wide licensing rights from **Electro-Thermal Industries** on an electro-thermal process that instantaneously reduces ores and oxides to metal.

EXPANSIONS. **Nuclear Metals, Inc.,** Concord, Mass., has dedicated its $2-million research-and-development lab. . . . **Standard Pressed Steel,** Jenkintown, Pa., has formed a nuclear components division for the production of control-rod housings, valve stems, bushings and other nuclear parts. . . . **Clark Bros.,** Olean, N. Y., division of Dresser Industries, has created a nuclear products dept. to produce turbo machinery and other equipment—John K. Hubbard will head the unit. . . . **Teleflex, Inc.,** North Wales, Pa., has formed a nuclear division under Eugene J. Messa to handle manufacture and distribution of its control systems. . . . An X-ray diffraction and spectroscopy lab has been established at Camden, N. J., by **RCA;** lab director will be Victor E. Buhrke. . . . **Components Corp.,** Denville, N. J., has formed a nuclear instrument div. under Jerry B. Minter. . . . Operation of a research-development lab for refractory products was scheduled on Dec. 1 by **Denver Fire Clay Co.,** Colo.; the lab's work will emphasis new products for nuclear-processing and other fields where high-temperature materials are needed. . . . Another Colorado firm, **Coors Porcelain Co.,** Golden, has reported development of a ceramic sponge to soak up radioactive wastes and bind them at 1,300° C for underground burial. . . . **Precision Technology, Inc.,** Livermore, Calif., has been acquired by **Librascope, Inc.,** Glendale, specialists in nuclear-weapons instrumentation. . . . **Sylvania Electric Products,** about to be merged with **General Telephone,** has opened a 48,000-sq-ft chemical and metallurgical lab at Towanda, Pa. . . . **Marman div. of Aeroquip Corp.,** Los Angeles, has entered the nuclear field with a product line that includes its "conoseal joint" for joining metal to metal; supervisor of sales-engineering is Gerald Forrest.

NEW BUSINESS. **Universal-Cyclops Steel Corp.,** Bridgeville, Pa., has a $3-million contract from the Navy to build an inert-fabrication plant for pilot production of molybdenum and other refactory metals and alloys. . . . **General Dynamics** has selected **Westinghouse** to develop rotating machinery for the gas-cooled reactor sponsored by the AEC/Maritime Administration. . . . **Allis-Chalmers** is manufacturing a barrel-type, single-stage, centrifugal compressor for the Gas-cooled Reactor Experiment (GCRE) in Idaho and a prototype, hermetically-sealed, motor-pump unit for the Hallam Nuclear Power Facility, Nebraska. . . . **Tracerlab's** Reactor Monitoring Center, Richmond, Calif., is building two retention-tank monitoring systems for the Instituto Venzolano de Investigaciones Ciertificos, Caracas, Venezuela.

FINANCIAL. **Nuclear-Chicago** reported record sales and earnings for the fiscal year ended Aug. 31. Sales totalled $3,851,078, up $1,265,248 from the previous year; earnings increased by more than 70%—from $252,946 to $442,252, or $1.41 per common share. Board Chairman and President James M. Phelan said company personnel had doubled in less than two years and that construction had begun on a 52,000-sq-ft building northwest of Chicago. . . . Also reporting record sales and earnings was **Baird-Atomic, Inc.,** for the fiscal year ended Sept. 30. Baird reported a backlog in excess of $2-million, plus the acquisition of a substantial minority interest in a firm producing scientific apparatus for teaching.

A NEW HIGH GAIN NON-OVERLOADING

LINEAR AMPLIFIER

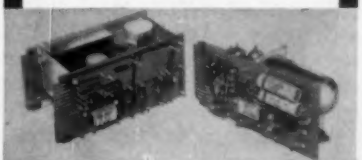
WITH

Building-Block

CONSTRUCTION

Eldorado's new Model LA-600 Linear Amplifier is a pulse amplifier designed for nuclear laboratory use. Patterned after the ORNL DD-2, the LA-600 incorporates a number of additional circuit and operational features.

Key feature is the use of Eldorado's unique building block construction. Major sections of the circuit are plug-in packages. Characteristics of the instrument can be altered by simply changing modules. In addition to the circuit flexibility, modular construction reduces weight and size, facilitates modification and maintenance, and minimizes obsolescence.



BRIEF SPECIFICATIONS, LA-600A*

MAXIMUM VOLTAGE GAIN	50,000
GAIN STABILITY	0.25% per week
OUTPUT VOLTAGE	Maximum — ±140V
OUTPUT LINEARITY	Integral — 0.15%
OVERLOAD RECOVERY	1000x Overload — 20 microseconds 200x Overload — 7 microseconds
OUTPUT PULSE CHARACTERISTICS	Pulse Width — 1.2 microseconds Rise Time — 0.2 microseconds
INPUT POWER	115/230 V, 50/60 cycles ac
PRICE	LA-600A — $595.00 LA-600B — $895.00 LA-600C — $650.00

*The LA-600B includes an integral/differential pulse height selector and has 1.0 microsecond double pulse resolution. The LA-600C is designed for use with Eldorado Model PA-400 Multichannel Pulse Height Analyzer.

Eldorado technical representatives are located in principal areas. For the name of your nearest representative and complete technical information, please address Dept. N-12.

Eldorado Electronics

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Covering for Surfaces Subject to Contamination

First application of Liquid Tile in a nuclear facility was made in the Decontamination Shop of Argonne National Laboratory (ANL). About 100 sq ft of concrete floor that is subject to spilling of caustics, acids and other decontaminating solutions, as well as the movement of heavy equipment, was sandblasted to remove the previous covering and to provide a mechanical bond for Liquid Tile. The new covering was applied in two coats one afternoon and was ready for use the next morning. Since then ANL has applied Liquid Tile to corridor floors of the Physics & Metallurgical Hot Lab, the entire poured-concrete exterior of the Plutonium Fabrication Facility, concrete floors and fuel-storage tank of the EBWR plant and concrete floors of the Argonaut reactor building. Liquid Tile, reinforced with PermaKote Fiberglas fabric, was also applied to the fuel-canal walls and floors at Shippingport Atomic Power Station. The area (25,000 sq ft) was covered in 15 days. The following are the steps involved: Fiberglas fabric strips are applied on a canal wall that has previously been covered with Liquid Tile primer; a saturated coat of Liquid Tile is rolled on and smoothed out; a final coat of Liquid Tile is applied. This thermoplastic, polyester-resin covering is also specified for the walls and floors of hot-cell water pits and floors of buildings in the Expended Core Facility of the Naval Reactor Facility at the National Reactor Testing Station.—Evershield Products, Inc., Joppa, Md.

Gamma Irradiator

Gammacell 220 is laboratory-size, self-contained, gamma irradiator with dose rates of >1,000,000 r/hr at center of 220-cu. in. irradiation chamber. Cobalt-60 source is arranged in squirrel cage configuration into which irradiation chamber moves by push-button control. Chamber is automatically returned from irradiate position after preset time. Access tubes to chamber permit irradiation of liquids or gases or incorporation of electrical leads.—Atomic Energy of Canada Ltd., P. O. Box 93, Ottawa, Canada.

Gamma-Spectra Analyzer

Medical spectrogammeometer is single-channel pulse height analyzer with linear or logarithmic count rate meter. Motor-driven potentiometer permits continuous spectrum scanning. Counterbalanced arm supports probe scintillation detector and suitable collimators for medical use (up to 60 lb). Vertical range of detector is from 24–60 in. above floor; horizontal range is 36 in. from center post.—Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.

Linear Amplifier

Model LA-600, patterned after ORNL DD-2, is nonoverloading linear amplifier featuring "building block" design. Model LA-600A is basic amplifier having approximately same performance characteristics as original DD-2. Model LA-600B includes integral/differential pulse-height selector offering improved double pulse resolution (1.0 μsec including differential discriminator).—Eldorado Electronics, 2821 Tenth St., Berkeley, Calif.

Manual Spectrometer

Model N-1260M is complete scintillation spectrometer for qualitative and quantitative analysis of energy spectra of gamma-emitting isotopes. Detector is completely enclosed in 2-in. sectional lead shield that reduces the background count to as little as 25 cpm with window fully open. Specifications are: energy range, 25 kev–8 Mev; long-time stability, 0.25% per day; linearity, 0.15%.—Hamner Electronics Co., Inc., P. O. Box 531, Princeton, N. J.

Insulating Material

Enrad I, form of irradiated polyolefin, offers improvements over polyethylene. Stabilized by irradiation prior to molding, Enrad I maintains characteristics at temperatures where polyethylene materials flow like liquid. Compared with both regular and linear polyethylene, it provides better rigidity, higher tensile strength and form stability to 300° C even after extended exposure to temperatures as high as 250° C.—Enflo Corp., Fellowship Road and Route 73, Maple Shade, N. J.

G-M Scaler

Model 123 G-M scaler has glow-tube, five-digit capacity with no mechanical register required. Count capacity is 99,999 counts; resolving time is 150 μsec; input sensitivity is −¼ v; high voltage supply range is +500–+2500 v.—S. Gunnar Myrbeck & Co., Inc., Box 232, Quincy, Mass.

Radiobiology Services

Phagocytic activity measurements with radioactive colloids for endocrinological and pharmacological research are offered. Comprehensive radiation

measurement laboratory is available for radioactivity determination as well as for bioassay and tracer studies with radioisotopes.—Dept. of Biology and Medicine, Section 1-P, Nuclear Science & Engineering Corp., P. O. Box 10901, Pittsburgh 36, Pa.

Leaded Gloves

Leaded Neoprene glove that provides effective protection against short-wave radiation is seamless. Protective gloves are of high density (3.95 gm/cm³) and attentuate soft gamma rays as much as 86%. Gloves are 14–32 in. in length for dry-box work.—Charleston Rubber Co., Stark Industrial Park, Charleston, S. C.

Data-Handler

Digital Data Recorder-Transcriber (DDRT) can handle 100 pieces of information at once on each of 100 channels (basic rate 10,000 samples per sec). DDRT was originally conceived by Rocketdyne Div., North American Aviation Inc., which has licensed to manufacture and sell. As many as 4,800,000 separate items of information can be processed in 8 min using 10½ in. reels of standard magnetic tape. With thinner tape, reel will run 12 min and scan 7,200,000 items.—Davies Laboratories Div., Minneapolis-Honeywell Regulating Co., Beltsville, Md.

Personnel Monitors

Model ALM-2X detects and measures beta-gamma contamination on hands and feet. Model ALM-1X detects and measures alpha contamination on hands. Both models include, as standard equipment, external probe with 5-ft cable for checking clothing, hair, face, etc.—Technical Associates, 140 W. Providencia Ave., Burbank, Calif.

Scaler Converter

Model SCC-11 converts any scaler into alpha counting system. It plugs into any make or model scaler and detects only alpha radiation in prepared solid or liquid samples up to 2¼-in. in diameter by ⅛ in. by activated ZnS scintillation detector. Unit can be decontaminated in 5 min.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Scintillation Transducer

Model NST2 scintillation transducer combines NaI(Tl) crystal optically joined to standard 2-in. photomultiplier tube. Housed in over-all antimagnetic shield, units are available with crystal diameters of 1½, 1¾ and 2 in. and lengths up to 3 in. Further variations include truncated conical ends, drilled wells, etc. Gamma-ray windows of 5 or 10 mils are also available.—Levinthal Electronic Products, Inc., Stanford Industrial Park, Palo Alto, Calif.

Electrometer

Dynacon is dynamic condenser electrometer particularly designed for soft beta emitters such as tritium, carbon-14, sulfur-35, etc. It will accept and measure samples in solid, liquid, or gas phase. It will handle range of activities of over ten million to one without absorbers or dilution techniques.—Nuclear-Chicago Corp., 229 W. Erie St., Chicago 10, Ill.

Ultrasonic Process Machines

Series 200 SonBlasters are laboratory-size ultrasonic cleaning and chemical-process investigation units. Model G-201 SonBlaster generator power output to transducer is 35 watts average and 140 watts pulse at 90 kc. Model G-202 SonBlaster is identical except that it has choice of four duty-cycle timers; 15 min, 30 min, 1 hr, and 2 hr. Stainless-steel transducerized tanks NT-201 and NT-202 have ⅓ and ⅔-gal capacity, respectively.—Narda Ultrasonics Corp., 118–160 Herricks Rd., Mineola, L. I., N. Y.

Laboratory Bath

Bath (above) contains both refrigerating and heating elements. Hermetically sealed refrigeration system uses Freon; two heaters are 500-watt immersion type. Temperature range extends from −29° C to +71° C, with accuracy of 0.08–0.25° C, depending on

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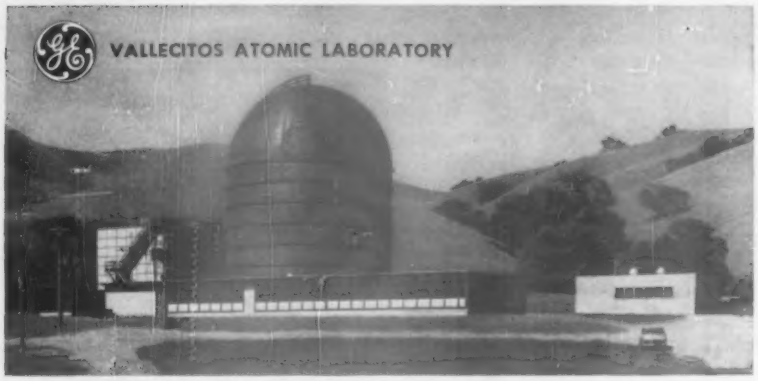

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PRODUCTS & MATERIALS

Department starts on page 88

temperature and bath capacity. Bath liner, pump casing and impeller are stainless steel. Pump capacity is 3.75 gpm.—American Instrument Co., 8030 Georgia Ave., Silver Spring, Md.

Geiger-Mueller Tube

Model GM4LB is G-M tube with low background count and capable of detecting beta radiation at energy levels of 0.1 Mev and above. Background response as low as 0.4 cpm is possible when operated in shielded enclosure with an anti-coincidence guard ring. Unit has thin aluminum end window 1 in. in diameter. Operation is at 1,200–1,400 with plateau length of 150–200 v and an average slope of 0.05% v. —British Industries Corp., Dept. K42, Port Washington, N. Y.

Pulse-Height Analyzer

Model 20609 has following features: up to 27-hr preset time during which background can be counted and later automatically subtracted from original run data; logarithmic readout on flat-faced cathode ray tube and strip chart recorder; dual-function high voltage supply; interpolation lights. All channels are printed out in <1 min.—Radiation Counter Laboratories, Inc., Skokie, Ill.

Transistor Tester

Model KP-2 transistor test set analyzes transistors at frequencies from 100 cps to 200 kc. It offers current range of from 100 μa to 1 amp with two regulated semiconductor power supplies for bias voltages and currents. Special models available for use up to 2 amp.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

C^{14}-Labeled Compounds

Iso-octane-C^{14} (or 2,2,4-trimethyl pentane-2,4-C^{14}) is offered free of both chemical and radiochemical impurities. Analysis by gas chromatography shows it to be identical with spectro grade 2,2,4-trimethyl pentane. Specific activity of the present stock is 2.86 mc/mM. Higher specific activities up to 5 mc/mM can be provided.—Research Specialties Co., 2005 Hopkins St., Berkeley 7, Calif.

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Immediately available is variety of non-nuclear uranium products in ton quantities including sodium diuranate, ammonium diuranate, uranyl nitrate in

solution or crystals, uranium oxide in three different forms (UO_2, UO_3, U_3O_8), uranium tetrafluoride and uranium metal.—Davison Chemical Co., Div., W. R. Grace & Co., Erwin, Tenn.

Ultrasonic Tank

Ultrasonic processing tank has capacity of 5 gal. Stainless-steel treatment chamber is 14 in. long by 9 in. wide and 10 in. deep. It is heliarc welded and fitted with two welded, stainless-steel drain connections for recirculation of process liquids. It is fully powered by generator with output of 400 watts continuous at 20 kc/sec.—The General Ultrasonics Co., 67 Mulberry St., Hartford 3, Conn.

Survey Meter

Model FNS-3 fast-neutron survey meter features large neutron-sensitive crystal and detects fast neutrons in presence of gamma radiation by proton-recoil principal. Scintillator is optically coupled to flat-face photomultiplier. Fast-neutron flux is indicated on 4-in. panel meter. Neutron-energy response is <0.5–14 Mev. Sensitivity is from 5–10^4 n/cm²/sec over three ranges.—William B. Johnson & Assoc., P. O. Box 415, Mountain Lakes, N. J.

Air Sampler

Model HAS-4 high-volume airborne particulate sampler is built around turbine-type blower with suction up to 75 cfm as measured by self-contained variable orifice meter. Instrument can be used for random or round-the-clock sampling, indoors or outdoors, and comes with choice of filters for alpha, beta or gamma counting.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

Periscope/Borescope

Omniscope has 180-deg hemispheric field of view. It can be furnished in lengths up to 40 ft, with offsets and angles to suit configuration of installation. Depth of field extends almost over whole working range, from ¼ in. to infinity (focussing eyepiece is provided).—Lerma Engineering Corp., P. O. Box 168, Northhampton, Mass.

Scintillation Detector

Model DS5-1P is gamma-sensitive scintillation detector designed for medical diagnostic applications. It consists of basic probe, which may be adapted to alpha, beta, or gamma well-type counting; light pipe and 2 × 2-in. sodium

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iodide crystal; removable, convertible nose piece providing crystal side shielding; and three collimator inserts. These threaded inserts, 20-deg flat-field collimator, straight-bore collimator and focusing collimator, are interchangeable.—Nuclear Chicago Corp., 229 W. Erie St., Chicago 10, Ill.

Synchro Cyclotron

Synchro cyclotron (above) develops, for minimum energy of 150 Mev protons, internal beam exceeding 5 μa at final energy of 165 Mev. With magnet of 110-in. pole diameter, weight of iron yoke is ~650 tons, length is 300 in., width 110 in. and height 195 in. Gap is slightly less than 16 in. Maximum field strength in center of magnetic field is ~16,000 gauss. Power to coils is supplied by 500-kw convertor. Oscillator is ¼-wavelength system. Frequency range for protons is 25.2–20.2 Mc. For acceleration of deutrons, oscillator is adapted to frequency range of 12.5–11 Mc by inserting additional length of coaxial line. Modulation of frequency, provided by rotating condenser, is ~450 cps. Deflecting magnet offers possibility of deflecting external beam in two directions over angle of ±5–20 deg with respect to center line.—N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.

Permanent Magnetic

Model 104B is permanent magnet with field strength of 1,717.5 gauss ±0.1% and maximum field inhomogeneity at gap center of 40 milligauss (23 ppm) over 2-in. maximum dimension region. In effect a secondary magnetic standard, 2-in. thick by 10-in. diameter gap permits use of large samples and cryostating equipment. Other specifications include; proton-resonance frequency of 7.313 Mc/sec.; maximum field inhomogeneity of 10 milligauss (6 ppm) over 1 cm maximum dimen-

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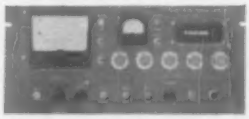

Model A309 Current Indicator and Integrator

1. **Measures currents from 1 milliampere to 3 milli-microamperes.**
2. **Integrates input current and registers accumulated charge.**

- Wide current range: 1 x 10-3 to 3 x 10-9 amp. in 12 switch settings.
- High accuracy: 1% at full scale.
- Internal calibrating current source to check proper operation.
- Front panel switch allows instrument to be used with current of either polarity.
- Pre-setting feature provides means of safeguarding against overexposure.
- Developed especially for use with Van de Graaff and other h.v. accelerators.
- Permits many experiments with particle accelerators that would otherwise be extremely difficult if not impossible.
- Register readout gives digital accuracy on charge measurement.

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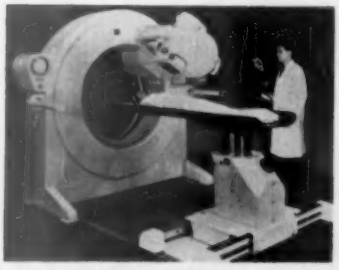
sion region; and maximum sweep amplitude of 40 gauss peak-to-peak. Series-connected sweep coils have resistance of 2,200 ohms and current sensitivity of 750 milligauss/ma.—Schlumberger Well Surveying Corp., Ridgefield, Conn.

G-M Counters

Nonphotosensitive, all glass, halogen-quenched G-M counters have transparent, nonmetallic, conductive cathode surface. Thin glass walls permit high-beta-radiation transmission. Counters have infinite life, no hysteresis and 200-v minimum plateaus with >3% slope and can operate up to 280° C for 250 days without change in operating characteristics.—Radiation Counter Laboratories, Inc., Nucleonic Park, Skokie, Ill.

G-M Survey Meter

"Sentinel," lightweight, portable, battery-operated survey meter, has choice of two, interchangeable probes: beta-gamma discriminating probe or end-window probe for alpha, soft and hard beta, and gamma detection. Radioactivity is indicated in three ways: by earphone, by flashing panel light and by six-range meter reading 0–50,000 cpm and 0–25 mr/hr.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.



Cobalt Therapy Unit

Newton Victor "Orbitron" cobalt-60 therapy unit (above) consists of (1) protective container to house cobalt and to collimate radiation beam, (2) annulus to which the container is attached so that it can be rotated about patient, and (3) treatment table. Sufficient space is provided to house source up to 2 cm in diameter by 3 cm long. Lead and heavy-metal shielding is sufficiently thick to reduce radiation to the values given below when total of 2,000 c is housed in container. (Self-absorption reduces radiation output so that effective value of source is about 1,500 c.) In "treatment" posi-

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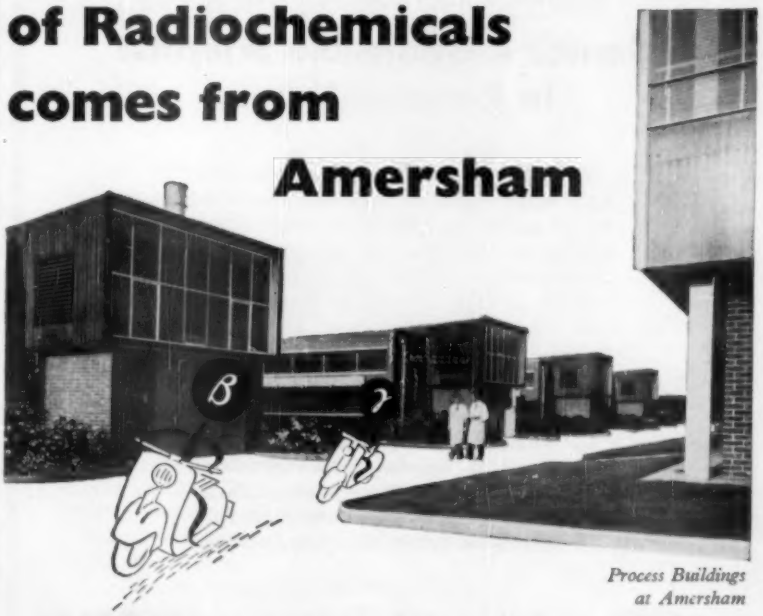

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PRODUCTS & MATERIALS

Department starts on page 88

tion, radiation is 2×10^{-3} r/sec (7.2 r/hr) 5 cm from outer surface. Radiation port limits beam to 30-cm diameter at 75 cm, with minimum width of beam 2 cm.—Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17, England.

High-Frequency Oscilloscope

Model 410 wide-band oscilloscope system has range from dc to beyond 50 Mc and direct-coupled, three-stage, balanced, distributed-type "Y" amplifier; high-speed sweeps, which can be driven at repetition rate as high as 250 kc, from 0.02 sec/cm to 0.01 μsec/cm in 20 variable steps. Other features include pulse rise time of 7 mμsec, built-in attenuator that provides sensitivity ranges of 0.2–200 full scale, and a-c/d-c sync circuit that offers level selecting of any portion of sync signal to trigger sweep.—Allen B. Du Mont Laboratories, Inc., 750 Bloomfield Ave., Clifton, N. J.

LITERATURE AVAILABLE

Stainless-steel castings with unusual hot strength is subject of 2-p. reprint.—Cooper Alloy Corp., Hillside, N. J.

Instruments for reactor control, nuclear physics, radioactive ore survey, etc., are described in loose-leaf Catalog EN.58.—Etelco Ltd., 22 Lincoln's Inn Fields, London, W. C. 2, England.

Closed-circuit TV booklet, "What Closed-Circuit Television Means to You," is offered.—Blonder-Tongue Laboratories, Inc., 9 Alling St., Newark 2, N. J.

Radiochemicals and biochemicals prices are listed in 21-p. pamphlet.—Schwarz Laboratories, Inc., 230 Washington St., Mount Vernon, N. Y.

Carbon-14 labeled compounds are given price list.—Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

"High-Vacuum Vapor Pumps" is title of 68-p. Bulletin 6-1 that discusses key to high vacuum, gives performance characteristics and tells how to select pumps.—Consolidated Electrodynamics Corp., Rochester 3, N. Y.

Plate and sheet-metal fabrication fa-

cilities are depicted in 15-p. brochure. —Littleford Bros., Inc., 457 E. Pearl St., Cincinnati 2, Ohio.

"Ultrasonic Cleaning" is title of 24-p. Bulletin S-200 that explains practical applications and basic principles as well as design of equipment.—Branson Ultrasonic Corp., 40 Brown House Rd., Stamford, Conn.

Laboratory apparatus is described in 16-p. publication.—Scientific Glass Apparatus Co., Inc., 100 Lakewood Terr., Bloomfield, N. J.

Ultrasonic cleaners are described in Data Sheet 1500.—The Narda Ultrasonics Corp., 122 Herricks Rd., Mineola, N. Y.

Radiochemicals (C^{14}, S^{35}, P^{32}) are given price list.—Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.

Valve remote-control systems, including flexible shafts, rigid rods and geared joints, are depicted in 20-p. Bulletin 5811.—Stow Manufacturing Co., 443 State St., Binghamton, N. Y.

Hot-lab instruments, remote-control stereomicroscope and metallograph, are described in manual.—Bausch & Lomb Optical Co., 85049 St. Paul St., Rochester 2, N. Y.

"Particle Accelerators" is title of 12-p. Bulletin B that describes many known and potential applications for both Van de Graaff and linear accelerators. —High Voltage Engineering Corp., Burlington, Mass.

Reactor control and safety system for the swimming-pool reactor at Delft, Netherlands is discussed in Vol. 19, Nos. 9 and 10 of "Philips Technical Review."—N. V. Philips Gloeilampenfabrieken, Eindhoven, Netherlands (U. S. distributor: Philips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.)

Laboratory apparatus are described in "New & Recent Devices" published periodically.—A. S. Aloe Co., 5655 Kingsbury, St. Louis 12, Mo.

Radiation-detection equipment is described in Bulletin PCC-58.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

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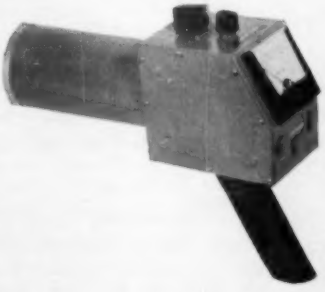

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PRODUCTS & MATERIALS

This article starts on page 88

alloy steel for radioactive, corrosive gases and liquids are depicted in 34-p. catalog.—Velan Steam Specialties, Inc., 37 S. River St., Plattsburg, N. Y.

Scintillation-crystal characteristics (anthracene and stilbene) are given in 2-p. Bulletin S-200-1.—Crystals Inc., 123 Woodland Ave., Westwood, N. J.

Research and development projects, facilities, services and capabilities are summarized in 23-p. brochure.—Avco Manufacturing Corp., 20 S. Union St., Lawrence, Mass.

Rare-earth and thorium uses in electronic industry and in ferrous and nonferrous alloys are subjects of three bibliographies.—New Process Metals, Inc., 45-65 Manufacturers Pl., Newark 5, N. J.

"Tracerlog" is title of external house organ published periodically.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Cast stainless steel properties and applications are given in 4-p. data folder.—Cooper Alloy Corp., Hillside, N. J.

Gas chromatography is subject of bibliography having 115 references.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

"Radioactivity at Work" is title of report of accomplished work published periodically.—Nuclear Science & Engineering Corp., P. O. Box 10901, Pittsburgh 36, Pa.

Geneva Conference papers available include "Research Experience with Plastic-Moderated Critical Assemblies," "Carbide Coatings for Graphite," "Reactivity of Uranium Compounds in Several Gaseous Media," "Physical Metallurgy and Properties of Zirconium-Uranium Alloys," "Recent Research in High-Level Gamma Dosimetry," "Effects of Alloying on the Kinetics of Oxidation of Niobium," "Preparation of Reactor Components by a Gas-Pressure Bonding Technique" and "Experience with a 1-Megawatt Pool Research Reactor."—Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.

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NEWSMAKERS

Thomas J. Foley, former Washington correspondent for the International News Service, has joined the Joint Committee on Atomic Energy to handle press relations. Another new JCAE staff member is **George Murphy,** who will handle administrative activities.

Eugene P. Wigner, theoretical physicist and Thomas D. Jones Professor of Mathematical Physics at Princeton Univ., accepted AEC's Enrico Fermi Award at a ceremony in Washington Dec. 2 (16th anniversary of Fermi's successful effort to get a chain reaction from his pile at the Univ. of Chicago). The award includes a medal, citation and $50,000.

Wigner

Lewis B. Werner has succeeded **Edward J. Brady** as scientific representative of the AEC in England. Brady has returned to the U. S. for a post in private industry.

New chief of the reactors branch, radiation div., U. S. Naval Research Laboratory, is **J. O. Elliot.** His staff includes two newcomers from Brookhaven National Laboratory—**Edward Prince** and **Don S. Harmer.**

Kenneth J. Culp has been named manager of marketing, atomic fuel dept., Westinghouse. A 10-year employee of the company, Fox will handle fuel sales, contract administration, application engineering and market planning.

Engineer-author **George Stern,** specialist in high-temperature and powder metallurgy, has joined Nuclear Development Corp. of America. Co-author of the book "Powder Metallurgy—Its Physics and Production," Stern joined NDA from American Sinsteel Corp., where he was technical director. He holds degrees from City College of New York and the Univ. of Michigan. He will manage NDA's materials department.

Stern

John G. Feldes has been named health physicist for the Enrico Fermi reactor near Monroe, Mich. Feldes was a health physics, special-materials and safety specialist with Argonne National Laboratory from 1944 until he joined the Fermi project in January, 1957.

Picker-X-Ray Corp. has elected **Ralph C. Schiring** to the presidency of its Waite Manufacturing Div., Cleveland; he succeeds retiring **Edwin C. Goldfield.**

E. B. Gunyou has taken over as chief of operations for Alco Products' atomic energy engineering dept.; he will supervise all engineering projects of the company in the nuclear field. Gunyou joined Alco from Koppers Co., where he managed the nuclear products operation. Earlier, he served in various engineering and managerial posts with Vitro Corp. of America and its rare metals div.

Gunyou

Sam A. Wenk has joined the consulting staff of Applied Radiation Corp., where he will be called on for advice on Arco's linear-accelerator-radiography work. Wenk is a past director of the Society for Nondestructive Testing and was formerly in charge of nondestructive testing research at Battelle Memorial Institute.

Wenk

The John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic, is continuing to attract some of the country's most respected scientists and engineers. Newest members of the research staff are: **Freeman J. Dyson,** a leading theorist in the field of elementary particle physics; **Robert R. Wilson,** an authority on proton-proton scattering; **David H. Gurinsky,** BNL metallurgist and authority on liquid-metal technology; **Werner B. Teutsch,** Tufts Univ. physicist; **John B.**

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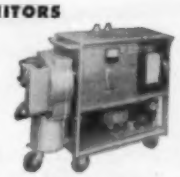

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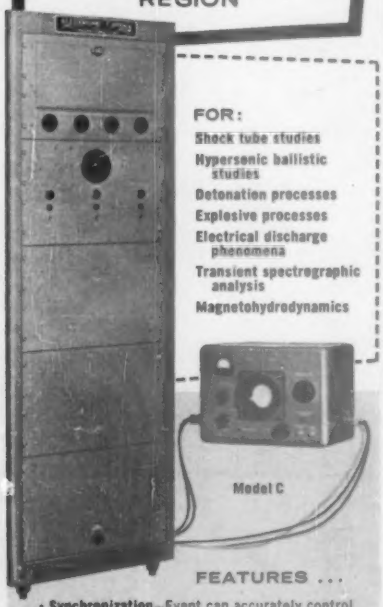

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NEWSMAKERS

Department starts on page 97

Sampson, a physicist formerly with General Electric; **Robert Katz,** a mechanical engineer; and **Alan B. Reidinger,** chemical engineer.

The National Bureau of Standards has chosen **Robert D. Huntoon,** associate director for physics, to fill a new post as deputy director to Allen V. Astin, NBS chief. Among Huntoon's former jobs at NBS have been: chief, atomic and radiation physics div.; and coordinator, AEC projects at the Bureau. He will handle day-to-day direction of NBS programs. Another staff note: **Peter J. Ausloos,** Belgian physical chemist, has joined the molecular structure and properties of gases section to work on determination of primary processes and the rates of elementary reactions in the photolysis and radiolysis of organic compounds.

Charles F. Cook has left Convair to join the research div., Phillips Petroleum, as manager of the new radiation lab at Bartlesville, Okla. New additions to the atomic energy div. are: **Richard Schmunk,** nuclear physicist; **James E. Crocker,** physicist; **William E. Radtke, Charles Smalling** and **Richard L. Beeston,** reactor engineers; **Robert E. Commander,** production engineer; and **Leonard L. White** and **Cloyd Moser,** health physicists.

Six nuclear specialists have joined the nuclear electronics dept., Hughes Aircraft Co. They are: **Stephen S. Friedland,** physicist; **Gerald H. Syrovy** and **V. E. Thompson,** mechanical engineers; **Valerie C. Burkig** and **Arturo Frisoli,** health physicists; and **R. Gilbert Downing,** electrical engineer.

William W. T. Crane and **Melvin Barmat** have joined the isotopic power dept. of Martin Co.—Crane as chief of advanced development and Barmat as project engineer. **Claude S. Burtnette,** former nuclear engineer with AEC, has joined the advanced design dept. (nuclear).

A long-time veteran of Maxson Construction Co.'s building activity in the nuclear field, **Joseph C. Smith,** has been appointed vice president for nuclear and heavy industrial construction. Smith participated in a six-year building program for AEC at Oak Ridge and at least four other nuclear projects.

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NUCLEAR CALENDAR

Jan. 22–23—Symposium on nuclear fuel cycles, sponsored by the Institute of Physics in London. Contact the Institute secretary, 47 Belgrave Square, London S. W. 1.

Jan. 26–29—10th Plant Maintenance and Engineering Conference, Cleveland (*Public Auditorium*). Nuclear session on maintenance in nuclear plants, Jan. 27. Contact Banner & Greif, 369 Lexington Ave., New York 17.

Jan. 28–29—First International Symposium on Nuclear Fuel Elements, Columbia Univ., New York. Sponsored jointly by Columbia and Sylvania-Corning Nuclear Corp. Contact H. H. Hausner, 730 Fifth Ave., New York 19.

Jan. 28–31—American Physical Society meeting, New York City (New Yorker). Contact APS, Upton, L. I., N. Y.

Mar. 31–Apr. 1–2—21st American Power Conference, Chicago (*Sherman*). Contact R. A. Budenholzer, Mechanical Engineering Dept., Illinois Institute of Technology, 3300 Federal St., Chicago 16.

March 31–Apr. 2—Symposium on millimeter waves, sponsored by the Defense Dept.'s research agencies and the Institute of Radio Engineers, New York City (*Engineering Societies Bldg.*). Contact Jerome Fox, Brooklyn Polytechnic Institute, 55 Johnson St., Brooklyn.

April 5–10—5th Nuclear Congress and Atom Fair, Cleveland (*Public Auditorium*). Contact T. A. Marshall, Jr., Engineers Joint Council, 29 W. 39th St., New York 18.

May 6–8—1959 Electronic Components Conference, sponsored by Institute of Radio Engineers, American Institute of Electrical Engineers, Electronic Industries Assoc. and West Coast Electronic Manufacturers Assoc., Philadelphia (*Benjamin Franklin*). Papers on instrumentation and control devices and radiation effects. Contact Bernard Osbahr, Electronic Industries, Chestnut & 56th Sts., Philadelphia 39.

May 30–June 5—5th World Petroleum Congress and Symposium on Applications of Atomic Energy to the Petroleum Industry, sponsored by the Permanent Council of the World Petroleum Congress, New York City. Contact C. E. Davis, gen. secy., 5th WPC, 527 Madison Ave., New York 22.

June 15–17—2nd International Symposium on X-ray Microscopy and X-ray Microanalysis, Stockholm, Sweden. Contact G. Hoglund, Institutionen for Medicinsk Fysik, Karolinska Institutet, Stockholm 60.

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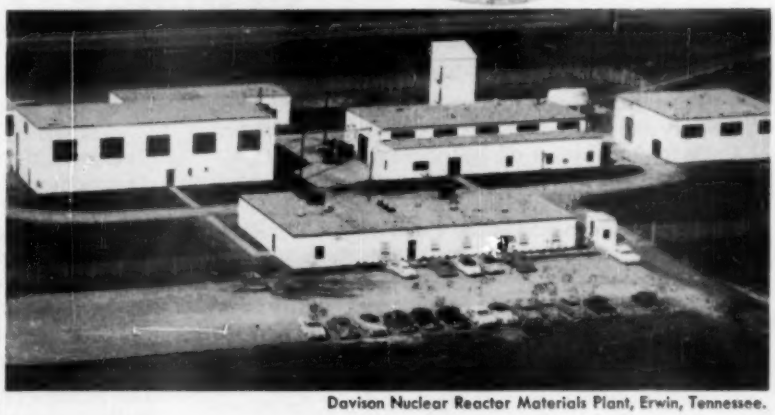

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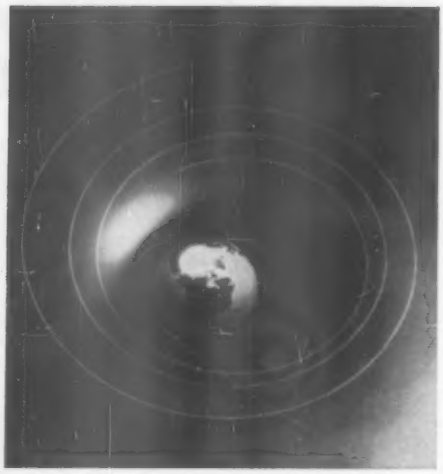

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(4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;

(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;

(6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency;

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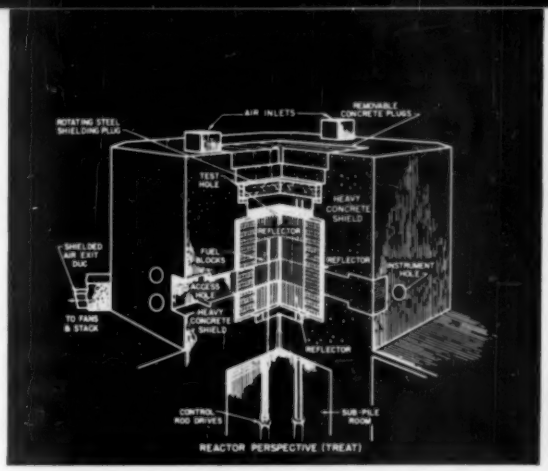

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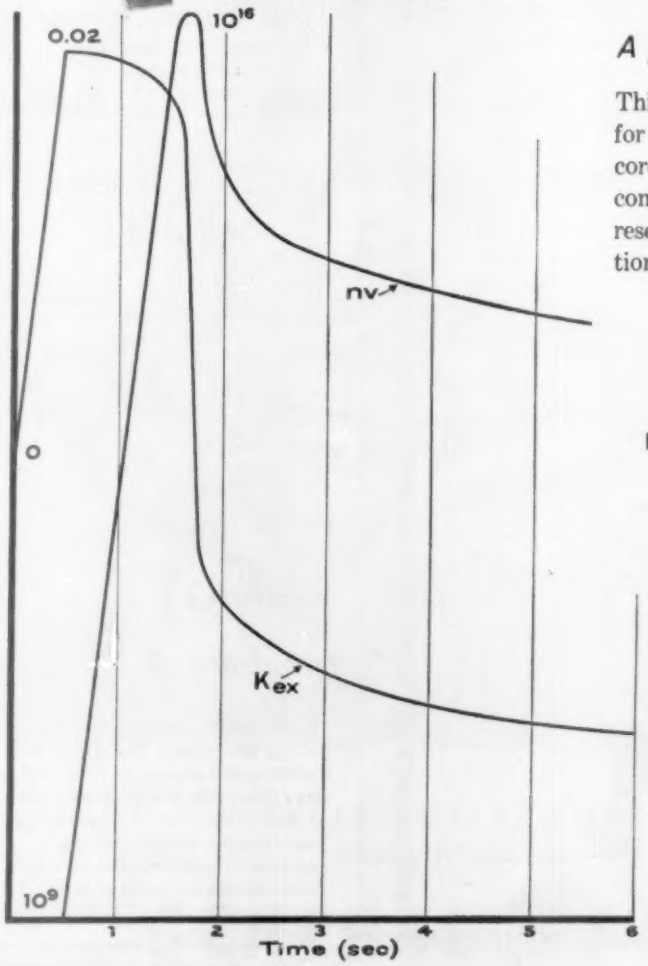

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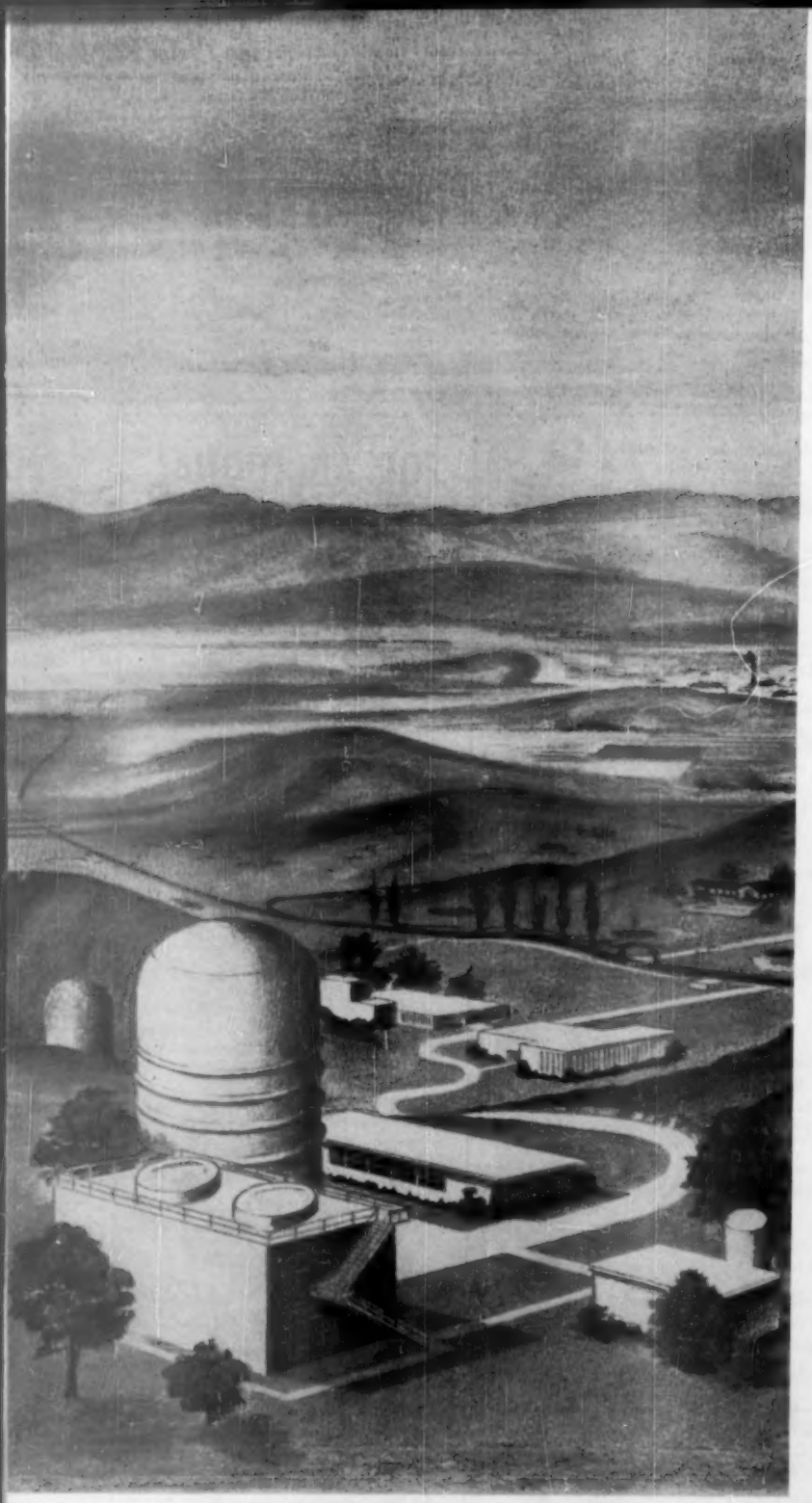

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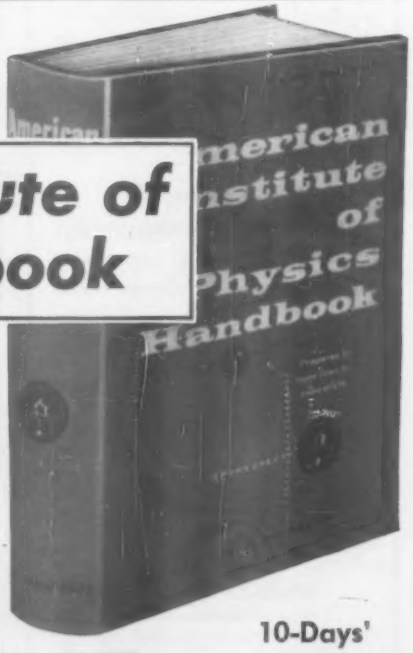

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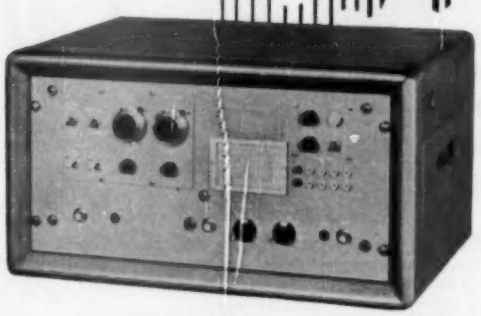

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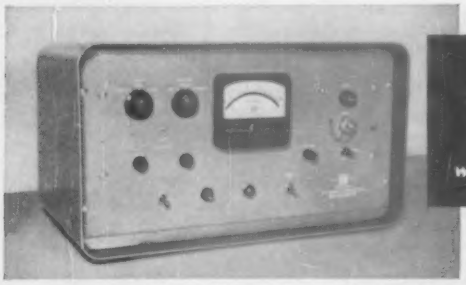

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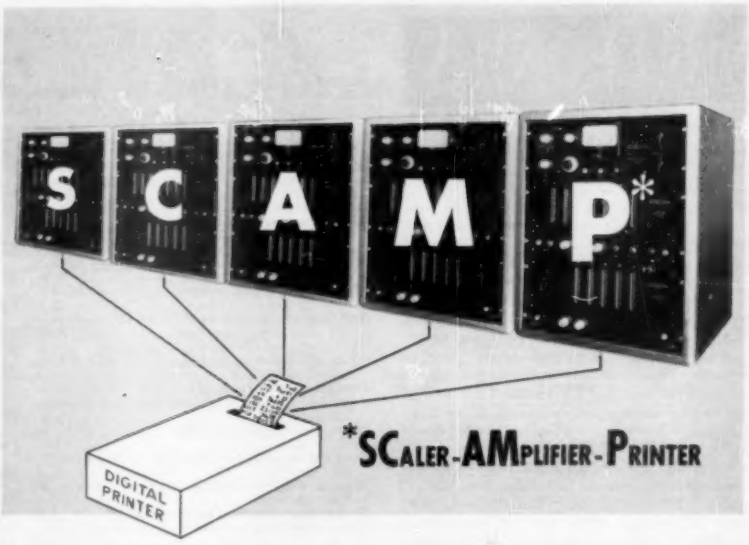

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Time Capacity: 1000 minutes (10,000 minutes—OPTIONAL).
Resolving Time: One microsecond.
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NUCLEONICS

INDEX to VOLUME 16, January–December, 1958

How to Use the Index

Following tradition, this year's index headings have been modified.

Again, cross-referencing is more elaborate, particularly in the areas of radiation applications and nuclear reactors. "Nuclear Reactors, Concepts," has been added as a category; "Nuclear Reactors, Power" has been subdivided into "Experimental" and "Full-Scale;" "Nuclear Reactors, Propulsion" is divided into "Aircraft," "Land" and "Marine."

Many countries are indexed individually, as are various organizations, e.g., the Atomic Energy Commission. However, company names can be found under the heading "Companies."

Significant elements can be found under their names, e.g., "Thorium," "Uranium" and "Zirconium."

Abbreviations used in the index refer to NUCLEONICS editorial departments, as follows: **AR**, Applied Radiation; **Edit**, editorials; **LE**, Letters; **NE**, Nuclear Engineering; **NEN**, Nuclear Engineering Notes; **PM**, Products and Materials; **R**, Roundup; **RR**, Reactor Roundtable; **TA**, Technical Advances; and **TH**, Thermonucleonics. Cross Sections, **CS**, was changed to Instrumentation and Measurements, **IM**, in the August issue; "corr." refers to article corrections published in subsequent issues.

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to 1,300° F) helium has been found more attractive.

The ORNL research program will concentrate heavily on fuel irradiation tests and structural materials development. The fuel program, which will be under way by the first of the year, calls for 70 experiments occupying space in four different test reactors; the plans involve static capsules, high-pressure thermal-convection loops and forced-circulation He loops.

Some specific points of interest that came out at the meeting were:

Pressure-vessel thickness limit. Experience at Bradwell has caused the British to be more optimistic about welding thick plate for pressure vessels in the field. They now feel confident they can handle pressure vessel thicknesses up to 5 in. In fact, the greatest difficulties now appear to be those of making thick sections that are free of laminations and shaped accurately enough so that they will align in the field.

Helium consumption. A not unreasonable question, if one is looking forward to a network He-cooled reactor power station, is whether there will be enough helium to go around. On the assumption that a full-scale reactor system could be made tight enough so that it loses only ½ (or 300,000 ft³) of its He charge every year, ORNL estimates that a network of gas reactors capable of supplying 10% of the nation's power would use up He at only 3–4% of the present rate of production. Put in another way, 50 full-scale reactors would after operating 50 years have used up less than 1% of our total He reserves.

UO_2 fission-product retention. Two UO_2 capsules irradiated by ORNL as part of the program mentioned above offer evidence that the UO_2 lattice will retain a much larger volume of fission-product gases than had been previously expected. Experimenters found that only about 1% of the Xe^{133} had escaped from the lattice in the two sets of specimens irradiated to 6,000 Mwd/ton and 10,000 Mwd/ton at a centerline temperature of 1,770° F. At the somewhat higher temperatures in a practical reactor design, ORNL hopes that "properly fabricated" UO_2 will retain 90% of the fission-product gases.

Gas-cooled breeders. Advanced design studies at Oak Ridge have been looking into the capabilities of the gas-cooled concept as a breeder working on the Th-U^{233} cycle. Calculations for idealized homogeneous graphite and pressure-tube D_2O designs predict breeding ratios slightly greater than 1.0. The net breeding gain, however, looks too small to provide the ten-year fuel-inventory doubling time needed to keep pace with expanding power demands.

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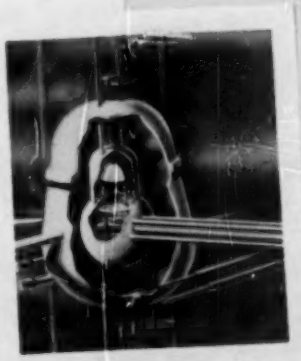
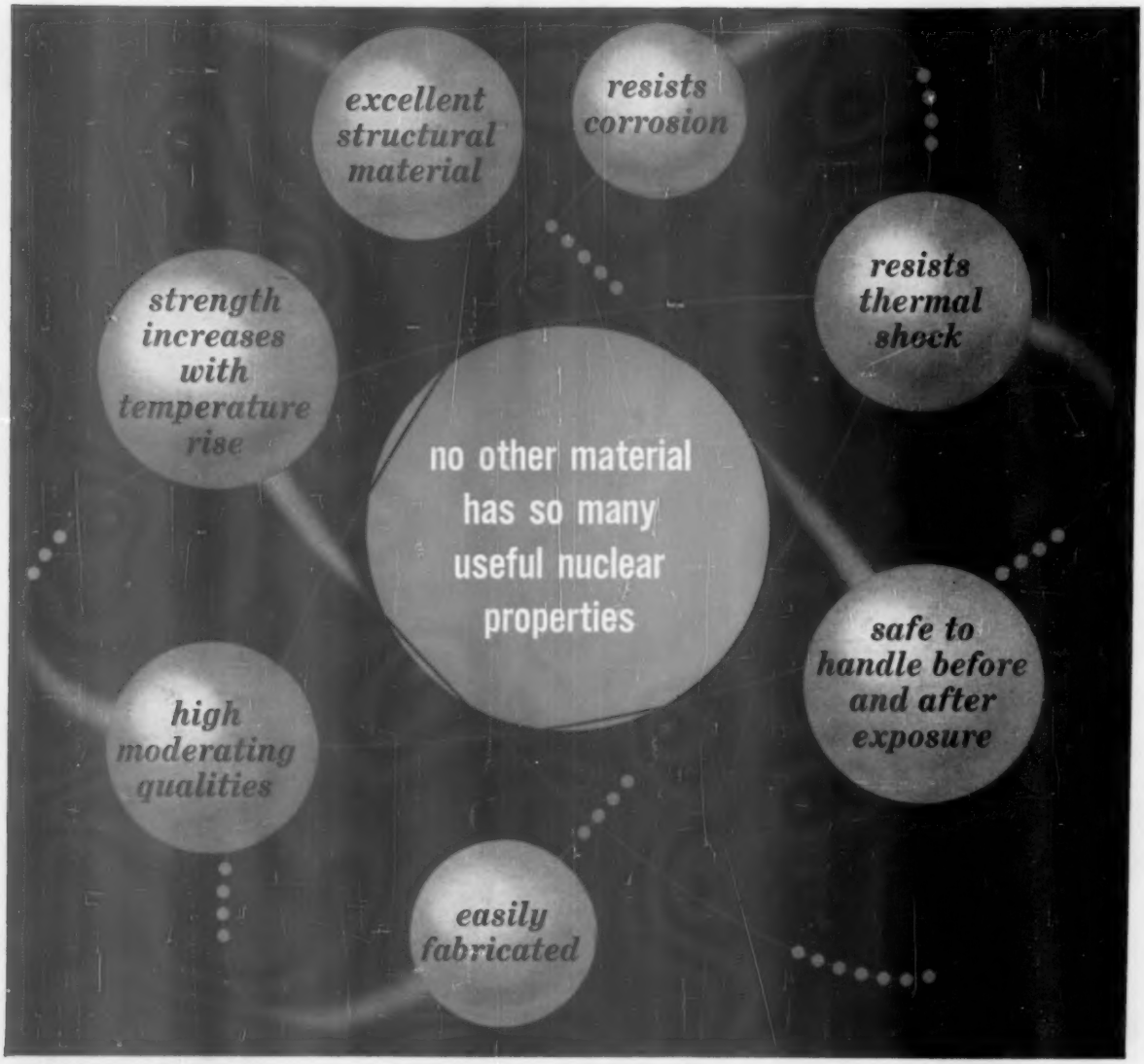
Please write: Mr. C. M. Newton, Personnel Office, Atomics International, 15330 Raymer Street, Van Nuys, California.

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